

SIM Report No. 10  
Scientific Investigations in Micronesia  
1949-

The Soils and Agriculture of Arno Atoll  
Marshall Islands

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by Earl L. Stone, Jr.

Pacific Science Board  
National Research Council  
N7-onr-291: T O IV & Viking Fund Inc.

SCIENTIFIC INVESTIGATIONS IN MICRONESIA

operates with financial assistance from  
Contract N7-onr-291, Task Order IV  
between

THE OFFICE OF NAVAL RESEARCH

and

THE NATIONAL ACADEMY OF SCIENCES

SIM has developed as a successor to the former CIMA project with an enlarged scope that includes field research in the physical, biological, and life sciences. Field work under SIM has been conducted in Guam, American Samoa, and in the islands of the Trust Territory in Micronesia since 1949 with transportation and facilities contributed by the Department of the Navy. The field research has been carried out in co-operation with universities, museums, research institutions, and Government agencies under this project of the Pacific Science Board of the National Research Council, supported by the Office of Naval Research and aided by financial assistance from the Viking Fund and other private sources.



THE SOILS AND AGRICULTURE OF ARNO  
ATOLL, MARSHALL ISLANDS. I. SOILS

SCIENTIFIC INVESTIGATIONS IN MICRONESIA

Pacific Science Board

National Research Council

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February 1951

#### ACKNOWLEDGMENTS

The writer participated in the 1950 SIM (Scientific Investigations in Micronesia) Project of the Pacific Science Board and the following report covers field work for the period 13 June - 5 August 1950. This project is supported by funds granted to the National Academy of Sciences by the Office of Naval Research, and the field work was carried out with the active assistance of the Navy Department, the Military Air Transport Service, and the officials of the Civil Administrative Staff of the Trust Territory (Navy).

Members of the Civil Administrative Staff at Kwajalein and Majuro were exceedingly helpful in many ways. The assistance of Miss Ernestine Akers, Honolulu secretary of the Pacific Science Board, greatly facilitated arrangements during our brief stop over there.

I am indebted to Dr. John W. Wells for an introduction to atoll geomorphology and for many stimulating conversations during the preparation of this report.

## INTRODUCTION

In preparing this field report I have had in mind the meager knowledge of atoll soils presently available and a realization that subsequent reports to technical journals are much more likely to be found and comprehended by soil scientists than by the laity. Therefore, the first section has been given over to a generalized discussion of soil formation on unraised atolls. The second section, the field report proper, is an account of the summer's work on the soils of Arno.

Part II, Agriculture of Arno Atoll, has already been prepared and because of this slightly illogical sequence a certain amount of overlapping and some minor discrepancies may be found in comparing the separate reports.

"The soil is fairly productive. Its larger islands are covered with grass, fine groves of coconuts, with magnificent breadfruit, Pandanus and Pisonia, and the usual belt of low growing vegetation growing upon the summit of the beach" -- Alexander Agassiz, of Arno Atoll in 1900.

## C O N T E N T S

### G E N E R A L

#### Land Formation and Destruction

FORMATION	1
DESTRUCTION	4
GROUNDWATER	6

#### Soil Formation

PHYSICAL AND CHEMICAL NATURE OF THE PARENT MATERIALS	8
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#### PHYSICAL FACTORS

<u>Solution</u>	11
<u>Cementation</u>	12
<u>Soil Movement and Burial</u>	14
<u>Shore Erosion and Storm Damage</u>	15

#### BIOLOGICAL FACTORS

<u>Organic Matter</u>	15
<u>Nitrogen Fixation</u>	16
<u>Seabirds</u>	17
<u>Man</u>	17

### S O I L S O F A R N O

TYPES AND MORPHOLOGY	19
----------------------	----

#### A. Soils Developed on Sands and Gravelly Sands

1. <u>Shioya loamy sand</u>	19
2. <u>Shioya gravelly loamy sand</u>	21
3. <u>Shioya sand</u>	21
4. <u>Arno loamy sand</u>	22
5. <u>Arno gravelly loamy sand</u>	25
6. <u>"L'angar gravelly sandy loam"</u>	26

B. Shallow and Stony Soils and Land Type	
7. <u>Phosphate rock complex</u>	27
8. <u>Dark shallow soils over sandstone</u>	29
9. <u>Stony and very stony complex</u>	29
C. Peats and Mucks	
10. <u>Mangrove peat</u>	31
11. <u>Mangrove shallow peat and rock complex</u>	32
12. <u>Mangrove muck</u>	33
13. <u>Coconut-pandanus peat</u>	33
14. <u>Taro pit muck</u>	35
D. Miscellaneous Land Types	36
SOME CHEMICAL PROPERTIES	37
<u>pH, Calcium and Magnesium</u>	37
<u>Salt Content</u>	38
<u>Organic Matter and Nitrogen</u>	39
<u>Phosphorus</u>	40
<u>Potassium</u>	40
<u>Manganese, Iron and Aluminum</u>	41
SOME EFFECTS ON PLANTS	41
DISTRIBUTION	
<u>Maps</u>	45
<u>Notes on Land Conditions</u>	47
APPENDICES	
A. SCIENTIFIC NAMES	51
B. DESCRIPTION OF PROFILES SAMPLED	52
C. REPUTED EFFECTS OF MANGROVE MUCK	54
D. DISPOSITION OF PLANT COLLECTIONS	55

## GENERAL

### Land Formation and Destruction

#### FORMATION

Land formation can be viewed as the culminating process in atoll development or as a minor consequence, a superficial collection of fragments that happens to protrude above sea level. In terms of mass the land is but an insignificant fraction of the atoll and occupies only a small part of the area. In discussing the soils of the atoll we unavoidably incline to the view that land formation is the culminating process but we will treat it here only to the extent necessary for an understanding of the soils.

There is no evidence that the present atoll surface has been uplifted. (See report of the Geologist.) For our purposes we will assume that the land has formed on a platform of consolidated material having an elevation at or slightly below mean low tide. Ordinarily this platform will be consolidated reef rock but occasionally it may be cemented sandstone or "conglomerate". The nature of this platform can be seen on the typhoon swept areas where land formerly existed and in exposures in the interior of Tinak, L'angar and Bikareij Islands. Although doubtless permeable to some degree this platform is considered much less so than the materials subsequently deposited upon it. On Arno there is no evidence that land has formed over unconsolidated materials and this possibility will not be considered further here.

Even the most cursory examination of the wider islands reveals that two major classes of materials have entered into their composition. Over the greater part of the atoll the seaward side of the land is composed largely or entirely of rock torn from the reef. Often these fragments have been rounded by wave action before deposition but again the pieces may have more or less of



their original jagged contour. Most of the rocky land appears to have been formed by the progressive outward building of a rampart composed of these coarse materials thrown up by storms. The younger age of the seaward side of this land is generally recognized and in fact rampart formation is in progress along much of the coast. Since it owes its formation to storms the surface of the rampart tends to mark the highest level to which the largest waves can carry coarse material. Thus this level is higher on the more exposed coasts subject to frequent storms, such as on L'angar Island, and it is lower elsewhere. Occasional great storms such as accompany typhoons may heap rock well beyond the edge of the rampart, even burying inland surfaces. In either case, included with the rock is a greater or lesser amount of sand and gravel ground from the rocks. Usually the stony land slopes downward slightly away from the coast, possibly because of weathering of the older materials.

It is not possible to say with certainty that the rampart is always the first formed land but in most cases it is difficult to postulate otherwise. Protected by the rampart, the quieter waters of the lagoon pile sand against it and the resulting sandy shelf often widens more rapidly than the outbuilding rampart. This process is particularly effective where the reef and hence the rampart, forms a sharp concavity. As is generally true along coasts, such embayments are more readily filled by wave-worn sediments and are protected from along-shore currents. The progressive widening of Arno Island, although now slow, is known to the people there because inland and parallel with the beach they find rows of pumice pebbles such as occur along the present beach.

Beach sands are not limited to the lagoon side of the land, although much more common there. On the seaward side the occurrence is most probable on lee coasts and again in embayments concave towards the sea. The narrow land just northwest of Ine village has a sandy seaward beach and in places the

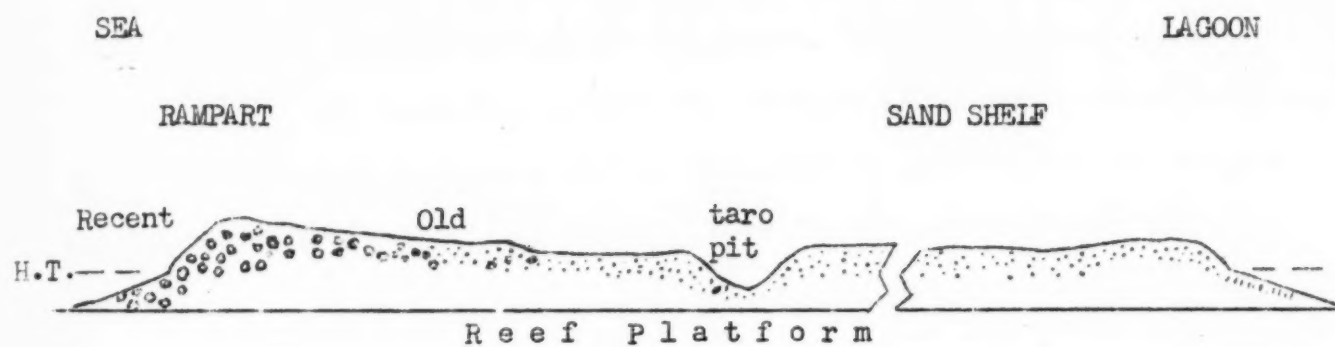
soils immediately back of the beach show signs of having been veneered with sand during storm periods. Although at first thought the height of sandy lands would seem limited to high tide level, wave action during storms continues to throw up sands and accumulation is doubtlessly aided by the effect of vegetation in reducing the outward drainage of waters.

The major element involved in raising the height of land, however, is the formation of sand dunes which are common along the windward lagoon shores. Dune formation proceeds most rapidly where a sandy beach is uncovered at low tide and exposed to the northeast trades. On Arno the maximum dune height observed was perhaps twelve feet above high tide though much higher dunes are known on other low islands in the Pacific. Occasionally small dune areas occur on the seaward side, as at one point on Bikareij Island where a small section of the low rampart has been buried. When supplies of sand are ample the speed of dune formation may be very rapid as exemplified by the high dune northwest of the wide part of Jab'u formed and vegetated since the typhoon of 1918.

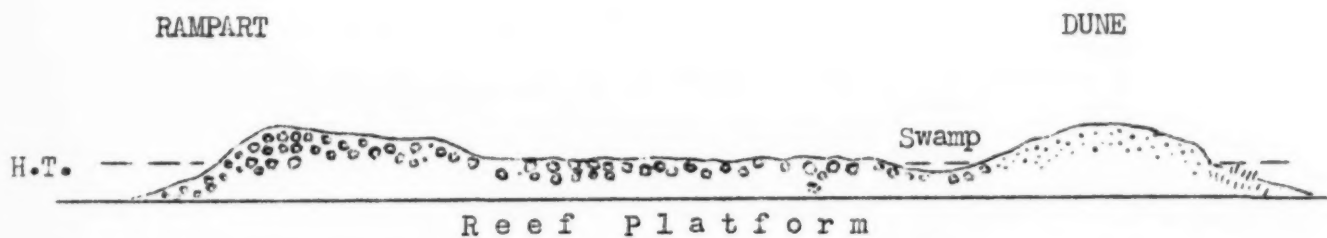
The three processes involved in building a rampart, sand shelf and lagoon dune may combine to give a land high on both shores and lower in the center. Such an orderly process of formation is far from common, as the cross-sections and soil maps reveal. Even apart from catastrophies, the vagaries of wind and storm bring cycles of addition and removal, often transferring materials from one point to another nearby. Dunes are often cut away or sometimes left inland when a new cycle of beach building takes place. Unfilled areas may be cut off from the sea by ramparts or dune ridges, giving rise to swamps or wet soils. A single minor storm may sweep away the accumulation of months or, again, heap fine materials on coarse or coarse on fine. The cross-sections of Figure I are diagrammatic sketches of conditions actually found.



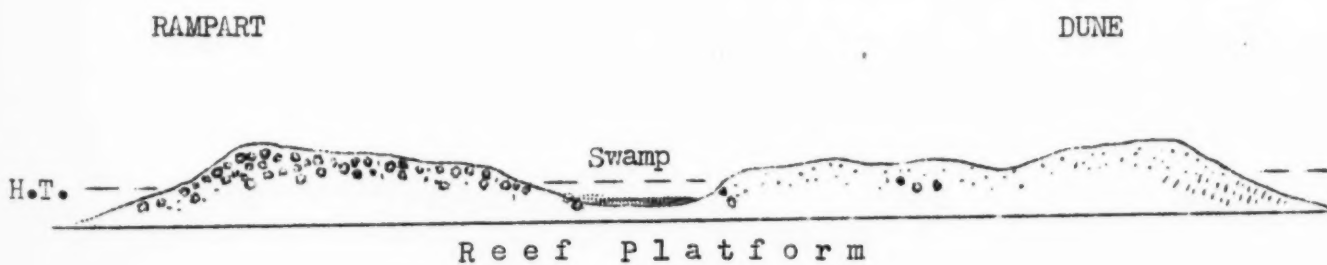
Fig. 1. DIAGRAMMATIC CROSS SECTIONS OF SOME ISLAND TYPES



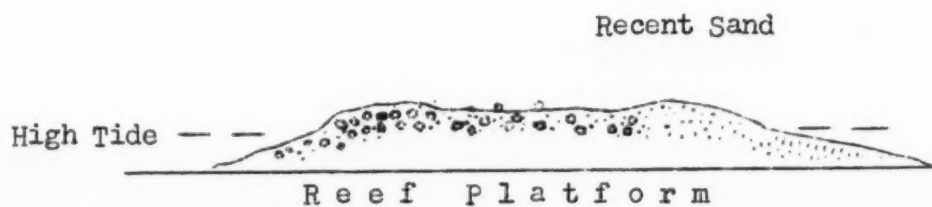
(a) Wide sandy island.



(b) Island with low stony interior.



(c) Island with enclosed basin.



(d) Narrow island.

Although the developing land is subject to the sea there are stabilizing influences that tend to protect its integrity. The slow outward and upward growth of the reef gradually reduces the violence of the waves which beat upon the land. Ramparts and dunes shelter the interior from all but the largest storms and as the land widens there is less likelihood that storm waves can sweep across it. Moreover, the shore itself comes to be underlain with a sandstone or conglomerate formed as outward flowing waters saturated with calcium bicarbonate cement the beach materials. The beach sandstone or conglomerate offers no absolute protection as many offshore blocks of these clearly show, but rapid formation helps to defend additions made to existing lands. The ground water may bring about cementation elsewhere than on the beaches and locally phosphatic cementation may stabilize loose materials.

The stabilizing effects of vegetation are obvious. The root mat binds the surface soil and the tops of plants both large and small reduce the violence of surface flow by wind and water, decreasing erosion and encouraging deposition. The stabilization is probably important in protecting ramparts and dunes but it is easy to overestimate the importance of vegetation; land also forms on dry atolls where the vegetation today is too sparse and small to have major effects.

#### DESTRUCTION

Despite the stabilizing influences above, the narrower lands cannot be made secure against destruction by major storms; in fact, on a geological time scale such lands may have a somewhat ephemeral existence. Typhoons are considered relatively rare in the southern Marshalls but are well known. Those of 1905 and 1918 have been well documented by the Germans and Japanese then resident. Lijömmar, an old man of Ine village, recalls four typhoons in his lifetime, including the above two, and knew of another in the days of his grandparents. For each of the four he described the windshifts and an intermediate

period of calm that indicate the passage of a typhoon center. Thus, it seems that typhoons and their attendant effects must be considered normal in the sequence of land formation.

On Arno the typhoon of 1905 was clearly the most destructive in a period of perhaps a century. Along the entire east coast of the atoll there was the long island of Namej (the Terranova of Agassiz), an unbroken land from the pass near the east end of Ine Island to the tip of present day L'angar Island. When the storm ended the wider portions of this island lay as isolated fragments, their centers intact. Much of the narrow land had been washed over by the great waves that cut away the land margins and replaced the former surface with primitive rock and sand. Other land had disappeared entirely, leaving the reef platform bare, perhaps as much as it had been before the land formed. In the subsequent 45 years this area has rebuilt to a considerable degree, with sand spits linking the individual islands and a rampart again manteling part of the bare platform. The same typhoon is said to have caused extensive damage on Ine Island; the narrow land between Ine Village and Jab'u was reduced in width and the effects are plainly visible in the condition of the narrower parts of the island from Jab'u west to Lukwoj<sup>"</sup>.

The 1918 typhoon was less destructive but left some effects. The small island of Enen<sup>"</sup>'edrik is said to have been separated from the southern end of Arno Island by this storm. The narrow land northwest of Jab'u was reputedly washed over for the second time by this typhoon and, at a point where the seaward reef is indented, the land was again trenched through to the reef rock below. Here is demonstrated one way in which typhoons destroy the land surface: The waves coming across the land from the seaward side began undercutting at the lagoon shore; the dense root mat of coconuts presumably held the surface layers but the sand below was readily washed away and thus a

shallow "waterfall" retreated across the island. For the most part this waterfall cut only about half way across the island and remains as a deeply scalloped escarpment, 3 to 4 feet high. The individual "scallop" are the "washout pits" that can be recognized elsewhere on Ine Island.

This area, like Namej, indicates rapidity of rebuilding; the channel has vanished entirely although its surface and that below the escarpment are lower than the former land. Along the lagoon shore a high dune has been built and now supports a young coconut grove.

#### GROUNDWATER

The groundwater is discussed in detail in the report of the Hydrologist and it is sufficient here to mention its existence. The classical Ghyben-Herzberg theory would picture a lens of fresh water floating in and on the salt water, both within a matrix of unconsolidated coral detritus that prevents turbulent mixing. It is evident that this view must be altered somewhat if we consider that the fresh water overlies a more or less impermeable platform beneath. The salinity of the groundwater is influenced by rainfall, of course, and so is subject to possible seasonal changes. Other obvious factors are distance from the shore and subsurface permeability, and the latter, in turn, is affected by the relative coarseness of the materials composing the land.



### Soil Formation

There are many different rainfall regimes throughout the Pacific and in consequence there are "wet" islands and "dry" islands, as well as others subject to periodicities of rainfall, either annual or at irregular intervals. It is quite obvious that moisture influences vegetation and leaching processes. In addition, the intensity and distribution of dry periods regulates soil salinity and the possible concentration or precipitation of dissolved substances. Thus it should be kept in mind that in the following we are principally concerned with a "wet" atoll having an annual precipitation of some 120 inches with a short and only "relatively dry" season.

Throughout the world there are areas of limestone resembling the atolls in chemical composition but uplifted for various periods. The soils developed on these indicate the course through which the atoll soils would pass if they remained above the sea for sufficient time. In the oldest such areas the calcium and magnesium carbonates, which make up such a large part of the present atolls, have been entirely dissolved from the surface layers and often from a considerable depth; the soil then consists of combinations of aluminum, silica, iron and other constituents originally present as only small percentages. The time required for such formation is great and the solution of several feet of limestone may yield only an inch or two of soil. In contrast the present atoll soils are extremely youthful and are classified as lithosols and regosols.

/1. The surface layers have been darkened by addition of organic matter and there has been some solution of carbonates but in the main the materials of the soils have been little altered.

/1 Lithosols "An azonal group of soils with little or no horizon differentiation ... if deeper, consisting largely of rocks and stones"

Regosols "An azonal group of soils with little or no horizon differentiation, deep ... over bedrock, and generally non-stony, consisting of materials such as loess, marine and lacustrine sediments and sands."

## PHYSICAL AND CHEMICAL NATURE OF THE PARENT MATERIALS

It has been mentioned that much of the sea-derived material is coarse but mixed with this is a varying proportion of fine gravel and sand.<sup>/2</sup> Here and there are beaches made up entirely of the finer materials. Many of the cobbles and jagged fragments are made up of somewhat porous corals which hold appreciable amounts of moisture and are penetrated by roots to some extent; thus they are more favorable for plant growth and rather more susceptible to disintegration than size alone would suggest.

The beach deposits formed along the lagoon shores vary in particle size from medium to very coarse sands, often with an admixture of fine gravel; locally they may consist of gravelly sands. The dune sands are finer and relatively uniform in size but mixtures occur when dune sands are reworked or washed over adjacent land. Soils formed from "coral mud" were not found at Arno but have been reported elsewhere.

The coarse materials are very largely composed of stony corals and Lithothamnion rock, whereas the lagoon sands contain a high proportion of Foraminifera tests and Halimeda fragments, as well as ground up coral and shells. Several investigators of "coral" reefs have pointed out that calcareous algae and other organisms often contribute more material to the reefs than the corals themselves; thus Mayor suggested that Rose Atoll was properly a "Lithothamnion atoll".

These distinctions become more significant when the results of chemical analyses of various organisms are compared (Table I). The inorganic parts of the reef building corals consist almost entirely of calcium carbonate, whereas some of the Lithothamnion group contain as high as 25% magnesium carbonate.

<sup>/2</sup> The U. S. Soil Survey classification delimits particle sizes as follows: stones (irregular) and cobbles (rounded), 10"-3"; coarse gravel, 3"-1/2"; fine gravel 1/2"-2 mm.; very coarse sand 2 mm.-1 mm.; coarse sand, 1mm.-0.2mm.

Another alga, Halimeda, however, contains only about 1% or less of magnesium carbonate. Moreover, the two minerals species of calcium carbonate, calcite and aragonite, which differ somewhat in solubility, are characteristic of different organisms. Some organisms that contribute little mass to the reef are nevertheless sources of certain elements, such as phosphorus, needed for plant growth.

Table I Range in Inorganic Composition of Some Marine Invertebrates  
After Clark and Wheeler (U. S. Geol. Surv. Prof. Paper 124, 1924) and Twenhofel (Principles of Sedimentation, 1939).

	CaCO <sub>3</sub> %	MgCO <sub>3</sub> %	SiO <sub>2</sub> %	Ca <sub>3</sub> P <sub>2</sub> O <sub>5</sub> %	(AlFe) <sub>2</sub> O <sub>3</sub> %	CaSO <sub>4</sub> %
Alcyonarian corals	73-99	.35-15.7	0.4-1.7	Tr-8.6	Tr-1.0	Tr - 5.4
Madreporian corals	98-99+	.09-1.1	0-1.2	0-Tr	0-0.7	0 - .2
Foraminifera	77-90	1.8-11.0	Tr-15	Tr	Tr-5.0	0
Echinoderms	78-93	5.0-15.0	0-10.0	Tr-1.9	0.1-5.2	Tr - 4.2
Mollusks	94-99.9	0-6.0	0-2.2	0-0.9	0.4-1.9	0 - 0.2
Crustaceans	29-83	3.7-16.0	0-3.8	8.7-27.0	.06-8.9	Tr - 5.3
Calcareous algae	74-99	.02-25.0	.02-2.1	Tr-0.4	.01 to 1.6	.03 to 1.4

Soils formed by weathering of consolidated limestones are not common on Arno and presumably this is likewise true of other atolls that have not been uplifted, since the primary zone of cementation is near tide level. The composition of cemented limesands and conglomerates resembles that of the unconsolidated materials but the former are obviously less suitable for soil and plant development. Such rock is usually permeable to some degree and roots and percolating waters soon develop numerous deep fissures and pockets of soil material.

Brown phosphate rock occurs on many low islands; this is formed by phosphate leaching from guano deposits into limy materials beneath and there forming insoluble calcium phosphates. The calcium carbonate is replaced wholly or in part by the phosphate and thus (excepting peat accumulations) acid soils, if found at all, occur on phosphate areas, e.g. Holei Islet, Palmyra Island, as reported by Christophersen (Bishop Mus. Bul. 44, 1947). During the replacement process the material is usually cemented if not already so, hence imposing the same mechanical limitations to plant growth mentioned above. The three small areas of phosphate rock observed on Arno, however, were highly fissured and contained pockets of unconsolidated sand.

Wave drifted pumice has been found on many low islands and locally its mass may be great enough to affect the soil or plant growth (c.f. the Funifuti report). On Arno, except to provide whetstones for the natives, its significance is probably nil; even where it appears most abundant its weight per unit land area is negligible. Low islands near volcanic areas may benefit from ash deposits but Arno is remote from these.

By the nature of atoll formation other rocks and minerals would not be expected, except for those transported by man or a rare erratic drafted ashore enclosed in tree roots. This expectation is not always a safe one: The sweeping conclusions concerning soil development drawn by Lipman and Shelley (Carnegie Inst. Publ. 340:201-208, 1924) from analyses of a single set of samples from Rose Atoll are entirely vitiated by the discovery of basalt fragments in the reef. Basalt had been reported by the Wilkes Expedition and by Couthovv long before, but these reports were considered erroneous by Mayor (Carnegie Inst. Publ. 340:73-79, 1924) who collected the material analysed. Subsequent collection by L. P. Shultz (Personal communication) has verified the presence of basalt. Likewise David and Sweet (The Atoll of Funafuti, Sect. V,



1904) present a soil analysis but note that a little of the soil from the sample locality had been brought in as ballast from Samoa.

#### PHYSICAL FACTORS

Once exposed above the sea the land materials are subject to the continuous action of atmospheric and biological agents. The first rains dilute and then rinse out the salt left by the depositing waves. On wet atolls this is repeated when salt is again added by storm waves, spray or evaporating brackish waters whereas on dry atolls the rainfall may be insufficient to remove the salt from the surface layers. Other substances, calcium and magnesium carbonates and the small percentages of other elements that occur with them or in the dead organic materials, are much more slowly dissolved by rainwater.

#### Solution

Nevertheless solution is the dominant physical process acting upon the land. The carbonic acid released by roots and organic matter decomposition or carried into the soil by rainfall converts calcium carbonate to the soluble bicarbonate which then moves into the groundwater. Some of this precipitates along the shores, cementing sand and rubble bare to the beachrock, but it is lost from the island interiors. We may calculate <sup>/3</sup> that carbon dioxide dissolved in rainfall before it reaches the soil is alone sufficient to reduce the land level about 1 cm. per century. This rate may be increased by a few to several-fold by the effects of living organisms and their decomposition products. The estimates of Sayles (Proc. Am. Acad. Arts and Sci. 66:380-467, 1931) on the weathering of consolidated windblown limesand in Bermuda indicated reduction of the land surface at the rate of 6.1 cm. per 100 years. This is little or nothing in one man's span but in a geological sense the process is rapid. Thus

<sup>/3</sup> 120" rainfall per year, solubility of calcium .52 millimols/liter at 25°C and .0031 atm. CO<sub>2</sub>, assumed density of the sand 1.8.

it appears that as an island widens with time so does its interior lower and a few millenia of such weathering would bring its surface to the level of the water table. There is no evidence that this has taken place on Arno atoll but the consideration again demonstrates the youthful condition of the land surface.

Solution progresses rapidly in the upper layers. The innermost margins of the belt of stony land are much less coarse than the outer beach for as they weather the large fragments give rise to smaller. The gravel-sized particles found within the upper organic horizon of the older soils are often soft and easily crushed, and frequently are penetrated by roots. Similarly, the sand particles are most disintegrated within this zone. On Arno the most highly weathered soils often contain much more gravel in the surface horizon than immediately below. Although other explanations are possible, the general concurrence of this suggests concentration of the gravel by solution of the finer particles.

#### Cementation

Except for beachrock formation, cementation by precipitation of dissolved carbonates in the upper few feet of soil is not of consequence under Arno conditions. Occasionally slight cementation of sand particles in the immediate vicinity of decaying roots was observed and in one instance slight cementation was noted throughout the sand overlying a buried organic layer near the groundwater level. There are, however, no "hardpans" or illuvial horizons within the soil proper on Arno nor would there be expected under the prevailing conditions of rainfall and parent material.

In a few profiles examined lagoon laid sands rested conformably on unweathered strongly cemented sandstone at a depth of 40" or more; likewise several wells penetrated to sandstone. In no case were these layers uncovered sufficiently to determine whether they lacked the slope characteristic of beach-

rock and hence it is uncertain whether they originated at the time of land formation or later. Near the boundary between Lukwäg and Kinajöng on Ine Island is a soft, relatively fine textured sandstone well above high tide level. This is thought to have formed in the lower part of a dune and subsequently been exposed by storm action.

In a sense cementation is merely an incidental consequence of secondary lime deposition and can be expected wherever water saturated with calcium bicarbonate evaporates or loses carbon dioxide, as by warming or escape of excess acquired under the higher carbon dioxide pressure in the upper soil.

In regions of scanty rainfall or frequent alternation of wet and dry periods cementation near the soil surface is possible and may account for the "hardpan" observed in the soils of Christmas and Fanning Islands by Christophersen. Baas Becking's ("The Soils of Coral Atolls", Preliminary Notes on Project E-6, South Pacific Comm., 1950) interpretation of such hardpan, however, suffers from some misapprehension as to the processes involved. One common mode of formation (e.g. the caliche of subhumid soils of the western United States) is through limited penetration of the scanty rainfall, the periods of wetting being followed by drying which causes precipitation of carbonates. Under particular climatic conditions such "hardpans" may be normal but their occurrence elsewhere ought not to be assumed.

Cementations by phosphates leached from guano deposits has been mentioned in the previous section.

Considerable care is necessary to distinguish between "hardpan" or indurated layers formed in the normal course of soil development and somewhat similar layers that originated otherwise and later, by exposure or burial, came to occur beneath a shallow soil horizon. For example, on Palmyra Island Christophersen described a profile with 10 cm. of "mold" overlying a 10 cm.

thickness of phosphatic "hardpan" which in turn rested on coral sands; almost certainly this is more truly seen as a shallow, highly organic soil layer developing on a thin bed of phosphatic rock. The rock, rather than the sand below, is the parent material of the soil and antedates it. Similar soils are found on Arno over deeper beds of phosphate rock which can in no sense be regarded as "hardpan".

#### Soil Movement and Burial

Likewise, burial of an existing soil, as by the debris thrown up in great storms, followed by soil development on the new material can give rise to an anomolous profile. Such a buried soil with a black horizon at the surface and a second dark horizon at some depth was found on Ine Island (Profile #4). A somewhat similar profile was described, although apparently not recognized as such, on Palmyra Island by Christophersen. Two profiles on Ile aux Canards described by Baas-Becking are almost certainly due to burial of a pre-existing soil, though he curiously regarded the dark layers at depth as illuvial horizons. Unpublished descriptions, photographs and analytical data from profiles taken on Canton Island by Dr. L. H. MacDaniels indicate that two of these have buried organic horizons.

In addition to burial of well developed soils small periodic additions of wind-blow or wave-flung sand on a vegetated area may result in a very considerable depth of "surface" soil colored by organic residues.

The importance of dune formations in raising land height has been referred to previously. Apparently there is little movement of sand inland beyond the dune under the usual Arno conditions where dunes are soon vegetated, thus increasing their effectiveness in trapping sand. Since windbreaks diminish wind velocities for some little distance to windward, as well as to leeward, it may be that tall vegetation, such as the palms, limits dune height.



Despite their texture, newly formed or sparsely vegetated dunes are subject to considerable slope washing during heavy rains. The sand eroded from the steeper slopes is deposited as the water sinks into the soil (Profile #27) and in fact effects a marked flattening of the inland dune slope. This process is intensified by clearing and burning in the coconut groves but the mixture of beach and dune sands found in stabilized soils near older dunes suggests that it has been of general occurrence. It is probable that rapid washing of sand excavated from the taro pits brought about the very gentle outer slopes of their surrounding rims.

Apart from slope washing, soil movement inland is of negligible proportions except near village areas where rain is concentrated in the hard-packed walks. The resulting accumulation of sand in low places nearby is of no consequence in soil development but numerous sand pits dug to resurface the walks provide excellent profile exposures.

#### Shore Erosion and Storm Damage

In addition to the drastic typhoon damage already mentioned, there may well be additional effects no longer obvious, such as saturation of organic exchange complex with sodium, etc. Unusual storms or a cycle of shore erosion may cut away the land to such an extent that soils of the interior are exposed along the beach and ultimately modified by the attendant changes in vegetation and environment. In consequence of typhoons and cycles of cutting and deposition, irregular patterns of micro-relief and soil distribution and occasional profile anomalies must be considered "normal".

#### BIOLOGICAL FACTORS

##### Organic Matter

From previous paragraphs it is already apparent that living vegetation and its disintegrating products contribute greatly to the solution of calcium

carbonate by their production of carbonic acid. Through penetration of roots this process may occur slowly even well within large pieces of porous coral. Baas-Becking has called attention to the abundance of algae which on Arno, as elsewhere on the moist tropics, mantle the surface of rocks and even the sand in open groves.

Apart from the effects on solubility the organic matter itself is of great significance in soil formation. In the absence of the more profound changes that mark mature soils, the presence of organic matter is the principal feature characterizing the atoll soil. It is obviously the principal source of cation exchange capacity. Further, the accumulation of nitrogen parallels that of well decomposed organic matter ("humus") for there is a fixed carbon-nitrogen ratio of approximately 10 or 12 to 1.

The breakdown of organic remains is carried on in large part by micro-organisms but earthworms are often abundant, and small snails locally so, in the darker soils.<sup>/4</sup> The earthworms are presumably significant agents in mixing the surface matter with mineral soil although root growth and decay provides another means of incorporation. Dead woody tissues are generally broken down by termites. In localized areas burrowing crabs accomplish very considerable mixing. Where excessive moisture prevents normal oxidation of organic materials these accumulate giving rise to peats and mucks, the distinction being the higher inorganic content of the muck.

#### Nitrogen Fixation

Baas-Becking has stressed the possible role of algae as nitrogen fixer and from soil samples collected by him a new group of nitrogen bacteria, *Beijerinckia*, has been isolated by Derx. *Azotobacter* has not been reported in atoll soils but would be expected in this habitat.

<sup>/4</sup> Collections of these were made by Dr. LaRivers.

On Arno legumes are common and nodules were observed on Vigna marina, Sophora tomentosa and Canavalia sericea. On the latter they occur on the smaller roots at some distance from the root crown and hence they may be easily missed. The Vigna seems particularly important for it forms thick masses in the open groves and extends aggressively onto sand beaches, old dwelling sites and burned areas. The two species of Canavalia, though less abundant, are vigorous vines in lightly shaded areas. Intsia bijuga is the only leguminous tree but its abundance in the original forest cannot be estimated accurately now.

#### Seabirds

Throughout the dry islands of the Pacific nesting seabirds have created guano deposits and highly nitrogenous soils. Under wet conditions such accumulations do not remain long but the numerous areas of phosphate rock are generally considered to have originated beneath such guano areas. As mentioned, the phosphate was precipitated as the insoluble calcium salt when carried into the calcareous material beneath, whereas the soluble nitrates were washed away. The resulting product is usually well cemented although unconsolidated brown sands may occur with the rock. Phosphate rock, guano, and soils strongly influenced by guano occur only where large numbers of seabirds congregated for long periods. Even away from these areas, however, the birds must have a very considerable effect on the soil. They are common in small numbers on many islands where they roost and nest (see report of the Zoologist); feeding along the beaches and at sea they are the only significant agents adding to the land from the fertility of the sea.

#### Man

Native man himself is a biological agent although the activities of the island inhabitants a century ago were more localized than now. Many of the soils that originated in dense native forests now support open coconut groves; it is

evident that such changes must profoundly alter soil properties but the extent of this cannot be well estimated. The taro pits are an obvious disturbance and the area influenced can be approximated grossly, but there is no way to recognize areas influenced by old house sites and fires.

Man also has an effect on the fertility levels of the soil which in the Marshalls, at least, is curiously counter to that of the seabirds. As the anthropologists have noted, the Marshallese went to the tidal beach or reef to defecate. This custom, however commendable as a sanitary measure, has meant continuing loss from the land of most of the nutrient elements contained in the diet. In Holland the soils about dwelling sites occupied for centuries have in some cases been colored by iron phosphates which accumulated through a concentration of phosphorus from the surrounding areas cropped by man and his domestic animals. It seems probably that the reverse has been occurring in various sections of Arno and its possible importance is greater because of the very limited land area occupied and the relatively dense population.

A recent source of nutrient losses is through the export of copra; for example, each ton carries away the phosphorus equivalent of 25 pounds or more of superphosphate.



## SOILS OF ARNO

The soils of Arno atoll have developed under a uniform temperature of about 81° F. and a rainfall approximating 120 inches per year, rather well distributed except for a drier period that usually occurs from January to March. As mentioned, the well drained soils are regosols and lithosols and even those called "well developed" are relatively primitive. In terms of profile nomenclature they are "A-C soils" with an A<sub>1</sub> horizon (zone of incorporated organic matter) and, usually, a narrow A<sub>3</sub> (transitional) horizon passing directly into the relatively unaltered parent material, the C horizon. As a group these soils are a tropical equivalent of the "humus-carbonate soils" of the European workers.

The soils of Arno were classified into series and types on the basis of common properties, particularly those relating to profile morphology. Complexes are recurring associations of various soil and land types that cannot be readily described or mapped as separate units.

### TYPES AND MORPHOLOGY

#### A. Soils developed on sands and gravelly sands.

1. Shioya loamy sand: This unit was first described on Okinawa and subsequently has been mapped on Saipan and several islands of the Pacific. It is a well drained alkaline soil formed principally on lagoon laid sands. The profile consists of a surface horizon 5 to 8 inches deep darkened by organic matter to a light gray, gray, or brownish gray color, resting on light-colored limesands. It is typical of the younger but not recent lands and is widespread particularly along windward lagoon coasts and on narrow lands; it is usually absent from the seaward coasts and wider island interiors.

A characteristic profile is as follows:

0 - 7" Friable loamy sand, dark gray (10 YR 4/1) <sup>5</sup>  
in color when moist, single-grained or weakly  
aggregated. pH 7.8

7 - 8" Transitional.

8 - 40" Single-grained pinkish white (7.5 YR 9/2) loamy  
sand composed of forams and ground shells, coral  
and Halimeda fragments. pH 8.4

On wider islands there is often a transitional zone between this unit and the Arno loamy sand inland. As mapped, the unit contains some areas of the Shioya sand, particularly along aggrading coasts.

The present vegetation of this unit is usually open coconut grove although small areas are in the mixed scrub forest (see Part II). *Scaevola*, *Messerschmidia* (*Tournefortia*), *Morinda* and *Guettarda* often form a dense undergrowth in poorly maintained groves. The ground cover depends to some extent on the degree of shading and presumably on salinity although this was not checked in the field. *Wedelia*, *Fimbristylis*, *Vigna*, *Triumfetta*, *Tacca*, *Centella* and the grasses, *Thuarea*, *Eleusine*, *Lepturus* and *Paspalum vaginatum* are often common in open groves. Under present conditions coconuts are certainly the most suitable crop for this land.

The groundwater underlying this soil may be fresh or brackish but it is doubtful whether the surface soils are normally ever very salty. Exposure and groundwater salinity affect the vegetation and hence, together with age, determine the relative development of the soils within this type. Under favorable conditions their development is fairly rapid; some areas swept by the 1905 typhoon and subsequently well vegetated were mapped as belonging to this unit, although recognizably younger than the modal profile.

Christophersen's descriptions, "sand of a lightish gray brown" on Washington Island, the "grayish brown soil" of the coconut plantations on

<sup>5</sup> The color names and the notations for hue, value and chroma are according to the Munsell system. Unless otherwise noted, they apply to dry samples.

Fanning Island and "lightish gray brown coral sand...mixed with root fibers, but still with a low percentage of organic matter." on the beach crests of Palmyra Island appear to place these soils with either this unit or the Shioya sand later described.

2. Shioya gravelly loamy sand: This type differs from the preceding chiefly in its content of gravel-sized fragments which may be of either lagoon or sea reef origin. Small areas of stony loamy sands are included. Most of the unit occurs on the narrow islands and part of it shows evidence of old typhoon damage.

The profile is similar to that of the loamy sand although sometimes more irregular because of the coarse materials. The vegetation is largely open coconut grove with vigorous invasion of *Scaevola* and *Messerschmidia* from the shoreline when clearing is neglected.

3. Shioya sand: The Shioya sand differs from the loamy sand in its lighter colored and generally shallower zone of organic incorporation; the textural distinction does not always exist. As recognized in the field this type includes dune sands, and medium and coarse beach sands, all of recent origin. Small areas of gravelly sand were not separated nor could a salty phase be recognized with certainty in the field.

The largest areas of this unit are recently vegetated swept lands and sands formed after the 1905 and 1918 typhoons. A belt of this type is commonly found between the sandy beaches and the Shioya loamy sand inland but is often too narrow to map.

A typical profile of the Shioya sand follows:

0 - 3 - 6" Single-grained pinkish gray (75 YR 6/2-7/2) (moist) sand or loamy sand, recognizably a mixture of decomposing organic matter, brown roots and white sand. pH 8.2. Changing abruptly through a narrow transitional zone to:

3 - 6 - 30" White or pinkish white (75 YR 9/1 - 9/2) limesand.

Areas of Shioya sand adjacent to the loamy sand usually have been planted to coconuts; elsewhere the characteristic vegetation consists of *Scaevola* and *Messerschmidia*, occasionally with *Pemphis* or *Suriana*, along the coast, and a mixture of young trees, such as *Calophyllum*, *Guettarda*, *Terminalia*, *Morinda* and *Pandanus*. *Triumfetta*, *Fimbristylis* and the grasses *Thuarea*, *Elaeagnus*, and *Lepturus*, and *Vigna* are characteristic ground cover plants.

In the main this type is regarded as a juvenile stage of the Shioya loamy sand. Its development varies with that of the vegetation it supports which, in turn, is restricted by salinity and lack of fertility. Development is most rapid when the soil adjoins older land and shares its outflowing groundwater, leaf litter and seed supply.

4. Arno loamy sand (tentative series): This is the well-drained, dark-colored calcareous soil formed on old beach and dune sands under the vegetation of the wider island interiors. This soil differs from the Shioya loamy sand in the dark color and very high organic matter content of the surface horizon (Table II). It is literally a black-and-white soil, with extreme contrast between the well defined surface horizon and the light colored limesands beneath. This unit occurs in the interiors of Arno, Tinak, Kilange, Bikareij and the several wider sections of Ine Island.

A representative profile is #25 from Arno Island:

- |           |   |
|-----------|---|
| Surface   | Scattered twigs and breadfruit leaves.  |
| 0 - 11"   | Highly organic, granular loamy sand or sandy loam, somewhat plastic when worked. Black when moist, very dark gray (10 YR 3/1) when dry, heavily flecked with lighter sand particles. pH 7.5. Earthworms abundant. |
| 11 - 13"  | Abrupt transition from above to   |
| 13 - 21"  | Single grained, light gray loamy sand stained with organic matter becoming white (10 YR 8/2) at a depth of a few inches. pH 8.4.  |
| 21 - 54"± | Friable, pinkish white (7.5 YR 9/2) limesand becoming coarser at 40".   |



Since the texture of the surface soil cannot be determined in the field because of the high organic content, the textural class is based on the underlying soil. Size of the sand fraction varies with origin, the beach deposits being coarser or less well sorted than the dune sands. The exact thickness of the dark surface layer and the thickness and color of the transitional zone varies; their combined depth may range from 7 to 20 inches in the profiles observed. The shallower depths are usually found near the lagoon shores where this type passes into well developed Shioya loamy sand, or near the margins of taro pits. Where gravel is present it is often much more abundant in the surface layer and is there highly weathered and frequently "rotten". Its greater abundance may result from the more rapid solution of the sand. The presence of relatively unweathered surface gravel can usually be related to former house sites.

Included in this unit as mapped are small areas of associated less well drained soils with similar profiles as well as a few areas of the Arno gravelly loamy sand and transitions to the Shioya loamy sand that were too small to be separated.

In almost all cases the groundwater beneath this unit is fresh or nearly so and the taro pits are located in areas of this type and the related Arno gravelly sandy loam. The peat or muck of the taro pit bottoms and the varied soils of the excavated slopes are also inclusions in this unit as mapped. The "spoil" from the pits forms at most a scarcely discernible bordering ridge and the profile resembles that of the surrounding areas, although often shallower.

This unit and the following also form a major part of the "breadfruit zone". Individual trees or small groves mixed with tall coconuts are characteristic although not always present. Pandanus is usually common and even in well cleared groves small trees or sprouts of *Allophyllus*, *Morinda*, *Guettarda* and

Pipturus are abundant. Untended groves are occupied by secondary forest, composed of the above species with others such as Premna, Intsia, and on Arno Island, Ixora. Wedelia grows as a rank herb in openings and with Ipomoea tuba climbs liana-like in areas of secondary forest. The three ferns, Polypodium, Asplenium and Nephrolepis are usually present, principally near the palm bases and on fallen palm logs; mosses are often abundant on these sites as well. Other ground cover plants vary with light intensity; under dense shade the ground may be quite bare or elsewhere sparsely vegetated with tree seedlings, Oplismenus, Ipomoea littoralis, small Tacca and scattered Thuarea and other grasses. In openings Tacca, Vigna and the grasses grow vigorously. The vegetation of the less well drained areas differs chiefly by the presence of Hibiscus tiliaceus and through the effects of dense shade.

Excepting the small areas of phosphatic soils, the Arno series with its less well drained associates are the most fertile soils of the atoll. The breadfruit grows rapidly here and bananas, papayas and limes grow fairly well, although severe iron chlorosis and probably other deficiencies retard their development when grown in cleared areas, as around the villages. Coconuts usually grow well on these Arno soils but on Arno Island itself a malady leading to early barrenness and death of the palms is associated with a portion of the unit. although not with its marginal occurrence or the bordering Shioya soils. In consequence, much of the interior there is now in breadfruit and secondary forests. According to the people this area was well populated for a long time prior to 1900; the malady was also present at that time and the coconut was maintained only by constant replanting.

The development and weathering exhibited by the Arno soils are evidence of their considerable age. They were formed under a native mixed broadleaf forest that was replaced in part by the indigenous agriculture and more or less

completely by "copra culture". Thus, their development cannot be related to the existing vegetation.

The generalized profile descriptions given by O. C. Rogers and by Alexander Spoehr for adjacent Majuro Atoll are essentially the same as that of the Arno loamy sand. C. S. Pearson, who has examined my photographs and samples of the Arno soil, states that it is the dominant type on Los Negros Island in the Admiralties.

5. Arno gravelly loamy sand: This unit resembles the previous soil but for the most part it has formed on coarse gravelly beach sands. These are usually of lagoon origin but some areas of highly fragmented outside shore deposits have also given rise to this type. The unit is usually associated with the Arno loamy sand in the wider island interiors but except on L'angar Island, is of much smaller extent on the islands mapped. It will probably be found more abundant in the chain of smaller islands around the windward rim of the atoll.

The profile is similar to that of the loamy sand except for the abundance of gravel, particularly in and on the surface horizon. Much of the gravel there is very rotten and readily crushed but the soil is always calcareous. The gravel of the deeper horizons appears little weathered.

Included with this unit as mapped are small areas of stony or coarse gravelly soils derived from mixed rampart materials but having a profile similar to the type. On Namwi Island a phosphatic soil resembling the Arno gravelly loamy sand in morphology (Profile #21) was not separated from it during the reconnaissance of that area.

The vegetation and uses of this unit are identical with those of the loamy sand except as it may occasionally overlies somewhat brackish groundwater. The presence of coarse material presents obvious difficulties in the use of hand tools.

6. "L'angar gravelly sandy loam": This name is used largely as a matter of convenience for the area of this unit actually observed is too small to warrant proposal of a new series. As the name suggests the unit occurs on L'angar Island where the type locality is marked by a protruding mass of old beachrock associated with a legend concerning discovery of the banana Jorukwor (see Part II).

A typical profile of this area follows:

- 0 - 20" Very gravelly moist granular sandy loam, plastic when worked, with only a moderate content of organic matter. Surface dark gray when moist, gray (10 YR 5/1) when dry but superficially appearing 6/1 because of the abundance of lime particles, changing to light brown-gray (10 YR 6/2) near the bottom of the horizon. pH of dry samples 7.7 - 7.8. The larger gravel is softened and much of the smaller (less than 1") is porous or rotten.
- 20 - 35"4 Very gravelly sandy loam appearing lighter colored than the above but with a moderate content of organic matter. When dry, light pinkish gray (7.5 YR 6/1) in color; pH 7.9. The lower part is heterogeneous, consisting of dark soil material mixed with roots and coral fragments. Bottom of profile not reached.

This soil has a more loamy texture in the deeper layers than any of the well-drained soils examined. As borne out by the analyses in Table II, the organic matter distribution of this soil differs from that of the Arno series in the relatively low (6.5%) content of the surface layer and a surprisingly high (4%) content of the organic matter at the 30" depth.

The mode of origin of this soil is not known but its inland position and the highly weathered gravel indicate considerable age. It is tentatively regarded as a down-drainage associate of the Arno gravelly loamy sand that occurs around it.

The present vegetation consists of abundant Hibiscus tiliaceus with a few tall palms and volunteer coconut seedlings, Pipturus, Morinda and a few bananas. Ipomoea tuba and Wedelia are present as climbers. According to the people this area is the "best place" for bananas and formerly many were grown here.



B. Shallow and Stony Soils and Land Types.

7. Phosphate rock complex: Three small areas of brown phosphate rock occur on Tak-lib, Namwi and L'angar Islands. The soils formed directly on such rock are usually very shallow, ranging from 2-10" in depth. Both rock outcrops and pockets of deeper soil are common. The soil properties vary; in the center of Tak-lib the shallow soil is highly organic and appears mucky when wet whereas on Namwi and L'angar Island the soil is granular and contains considerable brown phosphatic sand.

A characteristic shallow profile from L'angar Island is:

- 0 - 4"     Black, highly organic granular sandy loam.
- 4 - 6"     Dark brown, granular loamy sand consisting of organic matter mixed with coarse phosphatic foram sand.
- 6 -         Brown phosphatic rock containing large unaltered fragments of coral.

The shallow soils comprise most of the phosphate rock complex but associated with them are: (1) small areas of unconsolidated brown phosphatic sand, (2) adjacent limesands with the surface layer enriched in phosphorus, and (3) adjacent sands or gravelly sands with an admixture of phosphate throughout the profile. So far as observed, none of these three were sufficiently widespread on the atoll to warrant separate mapping and because of their affinities they are here considered as a part of the phosphate rock complex. Characteristic profiles of the latter two follow:

Profile #12 - (L'angar Island) limesand with surface influenced by adjacent phosphate deposits:

- 0 - 10"     Gravelly loamy sand, high in organic matter, granular, black when moist, very dark gray (75 YR 3/1) when dry. pH 7.4. Very possibly not conformable with the underlying sand.
- 10 - 20"+   White or pinkish white limesand free of gravel.

This profile was observed when traveling with a group of the L'angar people and its relationship to the adjacent phosphate area was not investigated

further.

Profile #21 - (Namwi Island) "Namwi gravelly sandy loam", a gravelly limesand influenced throughout by phosphate rock:

- 0 - 6-9" Well aggregated, very gravelly loamy sand or sandy loam, high in organic matter. Color very dark brown when moist, when dry dark reddish brown (5 YR 3/2) with particles of 5 YR 3/3 and 4/3 and some coarse white sand. pH 7.20. Earthworms abundant.
- 9 - 15" Light brown (75 YR 6/3) loamy sand, less gravelly than above, consisting of white and brown stained foram sand mixed with organic matter. pH 8.1.
- 16- 25"4 Pinkish white (75 YR 8/2) limesand with some rounded coral gravel. pH 8.1.

In appearance this latter soil is very similar to the Arno loamy gravelly sand and, lacking chemical data, the small area on Namwi Island was included with the surrounding Arno soils. The very large content of extractable phosphorus (Table II), however, indicates that this soil should be distinguished as a phosphatic phase or as a separate series.

The phosphatic area on Tak-līb Island supports a much battered remnant of the original vegetation, apparently the only such on the atoll. A few large *Pisonia*, *Cordia* and *Intsia* were noted here, as well as breadfruit and the introduced kapok, *Ceiba pentandra*. On the other two areas the vegetation does not appear to differ from the secondary forest found nearby and on Arno Island. Small trees of *Pipturus* and *Morinda* are abundant along with *Allophyllus*, *Pandanus* and large breadfruit and coconuts. Ground vegetation is sparse in the dense shade but the ferns, *Asplenium*, and *Polypodium*, and the climber, *Ipomoea tuba*, were noted near the profiles.

The people accompanying us on Namwi Island recognized that the deeper soils of the complex are favorable for plant growth and stated that "many" bananas were grown in this locality before the war. The complex should be favorable for coconut and breadfruit wherever the roots can reach a sufficient volume of soil.

Samples of phosphate rocks from each of the three areas were collected and will be analyzed. The deposits are too limited in area and depth to have appreciable commercial significance but the softer materials could be used locally as fertilizer.

8. Dark shallow soils over sandstone: The only area of this unnamed unit occurs in the center of Bikareij Island. Because of the rock beneath and its closeness to the water table, this soil is only moderately well drained. A characteristic "profile" is as follows:

- |        |   |
|--------|---|
| 0 - 6" | Highly organic, black, somewhat plastic sandy loam or loamy sand.   |
| 6"     | Calcareous sandstone, similar to that now found in the very shallow waters along the northwest shore of the island. |

Elsewhere the soil depth varies from 0 - 11". A retting pit, or "tou", quarried in the sandstone (perhaps as a well) at the margin of this area shows a 6-inch layer of sandstone overlying about 6 inches of unconsolidated or soft material, which in turn rests on hard sandstone. It is probable that the roots reach the intermediate layer through crevices. After heavy rains the water in this pit was fresh to the taste but is said to be usually slightly brackish. This is probably characteristic of the area in view of the elevation and location.

The unit as mapped includes small areas of mucky soil, one of which is occupied by a tangle of Clerodendrum. The remainder of the unit is largely in poorly kept coconut groves with an understory of secondary forest species, Allophyllus, Morinda, Guettarda, Pandanus and, in less dense areas, volunteer coconut seedlings. This area appears suitable only for the culture of coconut and pandanus.

9. Stony and very stony complex: This term is used to designate the belt of the soils and land materials formed by the outward building of a well

marked beach rampart on the seaward side of the land. Also included are similarly located areas covered with weathered irregular fragments of coral reputedly - and very probably - deposited by ancient typhoons. A "typical" cross-section from the windward beach inland, the synthesis of many observations, would appear as follows:

(a) Present beach rampart; recently deposited coral cobbles and rounded plates with coarse gravel and sand mixed in the lower parts; surface commonly six to ten feet above high tide.

(b) Twenty-five feet inland from (a); surface of rounded cobbles as at (a) but darkened by weathering; vegetation is tall *Scaevola* passing into *Scaevola-Pandanus* or *Scaevola-coconut* mixture inland.

(c) Hundred feet inland from (a); cobbles markedly weathered and covered with algae; many have lost their smooth and rounded surface. Vegetation is coconut plantation with *Polypodium*, small *Wedelia* and sprouts from cut stumps of *Scaevola*, *Guettarda* and *Morinda*.

(d) Two hundred feet inland from (a), near junction with sandy soils. Rounded cobbles are no longer recognizable; ground surfaced with very irregular weathered fragments of coarse gravel and small stone dimensions, heavily coated with black algae. Dark soil visible between fragments. Vegetation is coconut plantation, occasionally with breadfruit. *Polypodium*, *Nephrolepis*, and *Asplenium* are common, especially around the bases and moss-covered lower trunks of the palms. Other groundcover plants are chiefly sprouts and seedlings of *Morinda*, *Allophyllus* and *Pipturus*. The land surface is commonly two to three feet lower than at (b).

The profiles corresponding to the above stations show a progressive increase in the amount of organic matter and content of the finer particle sizes, associated with increased disintegration of surface rock. The change from (a)



to (b) is slight, principally the addition of a small amount of organic matter between the coarser particles. At (c) a black organic gravelly loam occupies the space between the weathered rock and all of the porous fragments are well penetrated by roots. At (d) the surface soil approaches that developed from gravelly lagoon deposits, although the deeper layers are not much altered. The coarser rock has broken down to weathered gravel and the percentage of sand and finer fractions have increased. Organic matter makes up 20% or more by weight of the material less than 2 millimeters in size, binding the mineral particles into aggregates.

Periods of rapid outbuilding, of stabilization or of beach erosion, as well as the overwhelming effects of infrequent typhoons, may disrupt any such orderly sequence and the "typical" cross-section above is less common than various atypical forms.

This unit appears fairly well adapted to coconut culture although the outer margins are often obviously less suitable than the remainder. In many cases the palms would probably benefit by retention of the surface organic matter and by effective windbreaks along the beaches.

#### C. Peats and Mucks.

10. Mangrove peat: This is a somewhat fibrous woody peat, moderately well decomposed and saline, formed under Bruguiera conjugata. When moist, it is dark red in color, drying to dark reddish brown (5 YR 2/2 - 3/2). The odor of hydrogen sulphide is present in the deeper layers. The fresh peat commonly has a pH of 7.2 to 7.4 but this changes to pH 5.6 to 5.9 upon drying. This type is usually less than 2 ft. in depth but the center of the large deposit on L'angar Island is deeper than 40 inches. The shallower areas are often somewhat more decomposed and may contain lime fragments. Limesand particles 1 to 2 mm. in size effervesce very slowly with hydrochloric acid,



indicating a considerable degree of weathering. The groundwater fluctuates with tidal changes but is usually 1 to 2 ft. below the surface. The principal areas of occurrence are on L'angar, Tinak, and Bikareij Islands.

The vegetation is unusual, approaching a monotype of *Bruguiera*. Along the margins *Lumnitzera*, *Pandanus* and the shrubby *Clerodendrum* may occur but transition from the upland is ordinarily abrupt and, except for a few epiphytic *Asplenium*, the interior vegetation is wholly *Bruguiera*. More than one age class may be present but the youngest, forming a low ground cover, is apparently short-lived in the dense shade. The forest is otherwise quite open beneath the canopy and presents a quite unusual aspect with innumerable crabs scuttling about the roots and "knees" that protrude through the cushiony reddish peat. This type is useful only as forest. The *Bruguiera* is a wood of value, strong and durable in contact with the soil and the younger stems provide long straight poles.

11. Mangrove shallow peat and rock complex: This unit sometimes borders areas of Mangrove peat and occupies the smaller salty depressions. The most common occurrence is a peat over and in the interstices of coral rubble or fissured rock; small areas of rock outcrop and of peat and muck mixed with coral gravel are also included within this type. The organic matter, if peat-like, resembles the Mangrove peat described above; the mucks, however, are blacker, more decomposed and perhaps less saline. The principal areas of occurrence are L'angar Island and Tinak Island and the borders of the north inlet on Bikareij Island, but small patches of an acre or less are met with elsewhere.

The dominant species is *Bruguiera* which may occur in pure stands. On Bikareij and Namwi Islands only, *Sonneratia* may be mixed with the *Bruguiera*. Elsewhere *Lumnitzera* and, on the margins, *Pandanus* are minor associates. The only use of such areas is as forest although retting pits are often located

within them.

12. Mangrove muck: This unit is properly a land type rather than a soil and occupies too small an area to warrant much comment. It consists of finely divided organic matter principally derived from *Bruguiera*, or *Bruguiera* and *Sonneratia*, mixed with limesand; it is saline, has a high water content and is flooded or nearly so at high tide. Mangroves grow only on the "drier" margins of the unit but the roots of *Sonneratia* penetrate outward in it for some distance.

The only appreciable area of this type occurs in the deeper basin at the south end of the north inlet on Bikareij Island. A portion of this is reputedly "bottomless", men having thrust sticks tied together to a depth of 75 feet from a canoe without reaching bottom. This had a familiar ring and our investigations showed a depth of some 4 feet of gel-like muck overlying rock in the center of the area. This is covered by perhaps six inches of water at low tide. On exposed margins where the spike-like *Sonneratia* "knees" arise the muck is two feet or so thick over sand.

Muck from beneath this surface smells very strongly of hydrogen sulphide. A sample taken from the center was dull red in color when removed but although tightly compacted soon turned gray throughout the entire mass. This area is noteworthy chiefly because of reputed effects of the muck on human skin (Appendix C).

13. Coconut-pandanus peat: This unit occupies an inland swamp on Ül-en' Island and is the principal type found in the old taro pits on Arno Island. The peat is shallow, usually 1 to 2 feet deep and fibrous, the more decomposed portions bound together by a mass of living and dead roots.

A description of the typical profile (#24, Arno Island) is:

0 - 24" Well decomposed peat with many root fragments; pH 6.5 at time of sampling, 5.4 after drying. Color after drying and grinding is brown to dark brown (7.5 YR 4/3). Water level at two inches at time of sampling following heavy rains; it stood much lower on a previous visit.

24" + Mucky limesand.

Conductivity measurements on the dry samples indicate that both the Arno and Ül-en' occurrences are fresh-water peats, although it is possible that the Ül-en' swamp may occasionally be subject to flooding with somewhat more brackish water. Included with the unit indicated on the map of Ül-en' is a small area of shallow black muck at the southeast margin of the swamp. In addition to woody sprouts, *Wedelia*, *Colocasia* and *Cyrtosperma* were growing at this point. People stated that these taros could not be grown elsewhere in the swamp although the water had "not very much salt".

On the remainder of the Ül-en' swamp the vegetation is coconut grove with an abundant undergrowth of pandanus. *Wedelia* and sprouts of *Morinda* and *Allophyllus* occur on the slightly higher rises. The peat offers poor footing for the coconuts; fallen logs are numerous and most of the standing trees are curved. Coconut usually grows on the margins rather than directly on the surface of the taro pit peats of Arno Island but the pandanus is in both positions. Here, too, *Hibiscus tiliaceus* is often a bordering tree and other secondary forest species around the margins contribute some organic matter. In both areas mosses and ferns, *Polypodium*, *Asplenium* and *Nephrolepis* are abundant on fallen logs although the ferns perhaps do not reach maximum development here. *Dryopteris goggilodus*, the "kinnen menuel", forms dense colonies in the Arno pits but was not seen elsewhere. Similarly *Eleocharis geniculata* was observed only on Ül-en' Island where it was fairly common on the peat surface near profile #26.

It is not known whether these peats can be utilized for taro culture. Both areas are subject to immersion after heavy rains and it is said that an attempt to replant some of the Arno pits failed because the small plants were covered with water. The potential fertility of the peat is high and cultivation, exposure to sunlight, etc., would gradually change the peat to the well decomposed muck in which taro normally grows. Palms are apparently growing well in the

Ül-en' peat although the yields are unknown. The possibility of excavating this peat for gardens is mentioned later.

As nearly as can be determined, the Arno pits were abandoned very early in the century and thus the rate of peat accumulation appears to have been extraordinarily rapid. According to Ralph McCracken, peat development in phosphate mining excavations on Angaur Island, in the Palaus, proceeds at a similar rate.

14. Taro pit mucks: If the area involved were more extensive a taro pit complex might be recognized. The steep inner slopes of the taro pits have been subject to slope wash and other disturbance from human traffic and the rooting of hogs. Not uncommonly coconut husks, fronds and brush from grove clearing are thrown over the edge and usually incompletely burned.

The pit bottoms are usually artificial mucks created by long continued additions of organic matter for taro culture. The mucks vary considerably in the admixture of mineral material and in relative "wetness". The groundwater is fresh and its level fluctuates with the tide, the maximum often being with a foot or less of the surface. After heavy rains many of the pits are shallowly flooded for a few days. As noted above, coconut-pandanus peat has formed in the long abandoned Arno pits. Elsewhere abandonment has been less complete or the water level unfavorable for peat accumulation. Taro culture continues in some pits.

A typical profile of a taro pit muck (#5, Ine Island) follows:

Surface	Scattered breadfruit leaves and seedlings of colocasia and a grass.
0 - 10"	Mucky limesand with some coral gravel less than 1 inch in diameter. Matrix very dark gray flecked with light lime particles. pH of moist sample 7.6.
10 - 32"+	Light gray changing to white sand, the organic matter content diminishing gradually with depth. pH 7.4 at 30 inches. Strong smell of hydrogen sulphide at 30 inches. Groundwater level at 28 inches when sampled but the following day, with the rising tide not yet full, at 15 inches.



Except on Arno Island the abandoned pits are often occupied by woody vegetation, such as breadfruit on "drier" sites and Hibiscus tiliaceus. One or two pits on Ine Island were completely dominated by Cyperus odoratus. The mucky pits could be readily returned to taro culture if the people wished to do so. In their present condition the drier mucks and pit margins are well suited for bananas but are utilized to only a limited extent for this purpose.

#### D. Miscellaneous Land Types.

These include the beaches, limesand drifts, and embayments or inland "flats" of sand, rubble or cemented rock. Since the fragmentation of the long eastern island by the 1905 typhoon much of the remaining land has been reconnected and augmented by wave heaped sands; the same process can be seen elsewhere as well. Where the surface of these rises above tide level it is vegetated by *Scaevola*, *Messerschmidia* and coconut seedlings, all often chlorotic in the early stages.

In the course of land formation or repair low areas of the island platform are sometimes cut off between the rampart or gravels thrown up along the seaward coast and the existing land or sand drifts on the lagoon side. This is the probable origin of many of the existing mangrove swamps and certain interior lowlands, such as that near Kinäjong. Rampart formation following typhoon damage has cut off two small basins on Aljaltüen' Mätol-en' and Enëräen' Islands; these are not yet vegetated. The larger "flats" of Namwi and Bikareij Islands seem to have been enclosed by extension of existing lands. As long as such areas are open to the sea the higher tides bring in sediments and occasionally rework the surface. Sand banks formed along the margin are rapidly stabilized by vegetation and thus young soils may come to occupy the interior as well as the periphery of an island.

Not otherwise described is the buried soil found 260 feet inland from the sea-beach near Ine Island (Profile #4, Appendix B). The present surface soil is



characteristic of a moderately well drained associate of the Arno gravelly loamy sand but extending from a depth of 35 inches to over 58 inches below the surface is a dark horizon containing organic matter. According to Lijömmar of Ine, a typhoon in the "time of his grandparents" threw up rock along the coast at this point and conceivably burial of the original profile occurred at that time. If Lijömmar's statement is taken literally, however, the maximum age of the present surface profile could scarcely be greater than 125 years, which appears too slight for the development noted.

#### SOME CHEMICAL PROPERTIES

The results of some chemical analyses of the mineral and organic soil samples from Arno are given in Table II. Descriptions of the profiles, identified by numbers, are given in the preceding section and in Appendix B. The material taken for analysis was that passing a 2 mm. sieve except for the organic samples of profiles #16 and #24 which were ground. pH was determined by glass electrode, soluble salts by conductivity measurements, total nitrogen by Kjeldahl, organic matter by the rapid microchemical methods of Peech (Soil Science 59:25-38, 1945), and the "readily soluble" amounts of other elements by the methods of Peech and English based on the use of Morgan's extracting solution (Soil Science 57:167-195, 1944).

#### pH, Calcium and Magnesium

As expected, the mineral soils are all slightly alkaline in reaction ranging from 7.2 to 7.5 in the highly organic surface soils to a maximum of pH 8.7 in the unweathered material lacking appreciable organic matter. These soils all effervesce with acid and hence analyses for available calcium were not made.

Dried samples of the organic soils have an acid reaction whereas in the field, using indicators, reactions vary from essentially neutral to slightly alkaline. Thus for the same samples:

Table II. CHEMICAL ANALYSES OF

Profile No.	Soil type or Designation	Depth of Sample Inches	pH	Organic Matter %	Total N %	OM/N	
25	Arno loamy sand Arno Island	0-6	7.45	16.68	.88	19.0	
		6-11	7.55	11.32	.59	19.2	
		14-19	8.40	.28	.04		
		24-30	8.65	.14	.04		
23	Arno loamy sand Arno Island	0-6	7.55	22.48	.98	23.0	
		12-18	8.25	.20	.05		
		30-36	8.40	.10	.05		
29	Arno loamy sand Jab'u Island	0-6	7.50	19.04	.88	21.6	
		18-24	8.40	.20	.04		
		30-36	8.50	.24	.06		
6	Arno gravelly loamy sand Ine Island	0-6	7.40	32.92	1.16	28.4	
		6-12	7.50	20.44	.70	29.2	
		20-26	8.35	.28	.04		
4	Moderately well drained associate of Arno very gravelly loamy sand Ine Island	0-8	7.55	16.88	.73	23.1	
		20-28	8.05	.80	.08		
		38-46	7.85	3.84	.13		
21	"Namwi gravelly loamy sand" Namwi Island	0-7	7.20	20.44	.67	30.6	
		10-16	7.50	3.44	.30		
		20-25	8.10	.52	.07		
12	Phosphate influenced asso- ciate of Arno sandy loam. L'angar Is,	0-8	7.40	19.36	.99	19.6	
11	L'angar gravelly loamy sand L'angar Island	0-6	7.70	6.52	.41	16.2	
		14-20	7.80	5.34	.34	17.3	
		29-35	7.90	4.02	.28	14.4	

# ANALYSES OF SOME SOILS FROM ARNO ATOLL

OM/N	Pounds per acre								Soluble salts Kx10 <sup>5</sup>
	P	NO N <sup>3</sup>	NH <sub>3</sub> N <sup>3</sup>	Mg	K	Mn	Fe	Al	
19.0	80	100	40	750	110	8	1	5	80
19.2	25	30	40	425	63	8	1	5	60
	25	8	18	5000	18	5	1	5	19
	40	8	20	3750	15	5	1	5	17
23.0	10	60	25	50	63	8	1	5	74
	25	8	15	3000	19	5	1	5	20
	25	5	15	4500	22	5	1	5	18
21.6	120	20	45	950	126	40	1	5	45
	50	5	25	4000	14	5	1	5	21
	60	5	22	5000	15	5	1	5	21
28.4	110	100	50	1800	203	25	1	5	104
29.2	25	40	45	750	80	20	1	5	74
	30	5	20	5000	18	5	1	5	15
23.1	25	25	35	50	135	25	1	5	46
	20	8	18	1600	23	5	1	5	24
	8	8	25	280	45	5	1	5	38
30.6	860	80	45	1120	286	5	1	5	104
	400	20	22	3800	45	5	1	5	57
	280	10	25	5000	31	5	1	5	32
9.6	210	70	45	1120	98	8	1	5	70
6.2	80	45	22	700	57	8	1	5	49
7.3	50	40	25	950	45	5	1	5	62
4.4	50	40	22	1000	55	5	1	5	115

Table II. CHEMICAL ANALYSES OF SOME

Profile No.	Soil type or Designation	Depth of Sample Inches	pH	Organic Matter %	Total N %	OM/N	P
14	Shioya sand. L'angar Island	0-7	7.95	1.82	.16		2
27	Shioya sand with recent overburden	2-1/2-4	8.25	.74	.08		2
	Jab'u Island	0-4	8.25	.70	.08		2
		16-20	8.70	.08	.04		2
16	Mangrove peat, L'angar Island	0-6	5.90		1.51		160
		16-22	5.75		1.24		120
18	Mangrove peat, Tinak Island	0-6	5.65		1.82		76
26	Coconut-pandanus peat, Ul-en' Is.	0-8	6.25		2.60		28
24	Taro pit coconut-pandanus peat, Arno Island	0-8	5.40		2.95		32

OF SOME SOILS FROM ARNO ATOLL (continued)

M/N	Pounds per acre							Soluble salts Kx10 <sup>3</sup>	
	P	NO <sub>3</sub> N <sup>3</sup>	NH N <sup>3</sup>	Mg	K	Mn	Fe		Al
	20	20	25	4250	31	5	1	5	29
	25	8	20	4000	25	5	1	5	18
	25	10	15	4000	19	5	1	5	20
	25	5	18	3000	12	5	1	5	17
1600		35	130	12000	976	5	1	5	2700
1200		15	100	16000	1200	5	1	5	3000
760		15	130	19000	1400	5	1	5	3000
280		30	190	2000	436	5	1	5	225
320		15	220	1400	310	5	1	5	345



Profile #	Fresh	pH	Dry
26	6.8		6.25
18	7.2-7.4		5.65
24	6.5		5.4

Changes of this magnitude or greater upon drying in mineral soils containing sulfur have been reported and are attributed to oxidation of the reduced forms to sulphates. This sequence is a very likely one in our samples and probably accounts for the increased acidity noted. The two samples of coconut-pandanus peat, #26 and #24, are the only soils on the atoll that were acid at the time of collection.

As might be expected from the discussion of parent material, readily soluble magnesium is relatively high in all soils.

#### Salt Content

The content of soluble salts is expressed as specific conductance,  $K \times 10^5$  at 25° C, of a 1:2 soil:water mixture (by weight). As a basis for comparing the samples of mineral soils from Arno, unfertilized leached soils of the humid regions commonly have K-values below 15 whereas heavily fertilized greenhouse soils may range from 100 to 200. A K-value of about 200 is about the maximum permissible for salt sensitive plants and values greater than 300 result in severe injury to common greenhouse plants. High organic matter contents raise the critical level at which injury occurred. For soils flooded with sea water the critical K-value is 100 for sensitive plants since the toxicity of a single salt is greater than that of mixtures.

Thus values for mineral soil in Table II fall within a range well below the level of plant injury. The higher values of the dark surface soils of the Arno and similar series is due in part to the content of soluble nitrogen salts.

The allowable levels mentioned above do not apply to the organic soils because of their very high moisture contents. The two samples of coconut-

pandanus peat fall well within the usual range of "fresh water" peats. The mangrove peats, of course, are highly saline.

#### Organic Matter and Nitrogen

The extreme color contrast between the surface and subsoil in the Arno series and its associates is paralleled by the contrast in organic matter content. That of the surface soils is surprisingly high, ranging from over 16 to nearly 33% in the surface six inches. Where this horizon is sufficiently deep for a second sample above the transition zone it, too, is high. Thus the average content of organic matter to a depth of eleven inches in profile #25 is 14% and 26.7% to a depth of twelve inches in profile #6. These values do not take into account the gravel excluded in sample preparation. Organic matter decreases very abruptly through the narrow transition zone and the white lime-sand beneath contains only a fraction of 1%. The notable exception is profile #4 where increased organic matter and nitrogen indicate a former soil surface long since buried by the material on which the present soil developed. Total organic matter as mass per unit area cannot be calculated without data on bulk density and excluded matter, but it would seem to be of the order of 200,000 to 400,000 lbs. per acre.

As already mentioned, the L'angar gravelly loamy sand has a relatively much lower content of organic matter in the surface horizon but the deepest samples taken still contain some 4%; again these values are on a gravel-free basis. The two samples of Shioya sand contain low amounts of organic matter.

In mineral soils total nitrogen generally parallels organic matter with the ratio between the two indicating the degree of decomposition. The OM/N ratios calculated do not depart far from 20, which is usually considered characteristic of well decomposed "humus". As might be expected, the amounts of "available" ammoniacal and nitrate nitrogen are moderately high in the dark surface soils and low in both the deeper horizons and in the Shioya sand.

Organic matter in the peat samples will be determined later but may be expected to exceed 80%. The total nitrogen contents are high, ranging up to nearly 3% for a sample from a taro pit on Arno Island. Of the available nitrogen forms, ammonia is far in excess of nitrate.

#### Phosphorus

Estimation of readily soluble phosphorus is an empirical procedure at best and the extractant used (pH 4.8) is not well adapted to calcareous soils. Thus the data presented characterize phosphorus status to only a limited degree. The low organic limesands of the subsoils and Shioya soils usually fall within a range of 20 to 30 lbs. P/acre (= 10-15 ppm) whereas the content of the dark surface layers is usually much higher, the notable exception being the 0-6" sample of profile #23 from the area of short-lived coconuts on Arno Island. The samples from profile #21 and #12, adjacent to phosphate deposits contain relatively large amounts of the element.

The quantity present in peat is generally several-fold greater than in mineral soils but by humid temperate region standards the phosphorus levels of the Arno peats are high.

#### Potassium

As with phosphorus the low organic limesands yield a minimal amount of potassium to the extracting solution. This value is about 15-25 lbs. per acre whereas the range in surface soils, having much higher exchange capacity, is commonly 50-200 lbs. per acre. These levels would be considered adequate for plant growth if they can be sustained but information on the reserve potassium is needed.

The mangrove peats are very high in potassium, reflecting the influence of sea water, and the coconut-pandanus peats are reasonably high.

### Iron, Aluminum and Manganese

The constant amounts of iron and aluminum in Table II are the minima reported by the procedure used and thus any lesser variations are concealed. A much greater range is shown by the manganese contents; the minimal amount, less than 5 lbs. per acre, characterizes the low organic limesands, the peats, and the high phosphorus soils but the remaining surface soils contain 5 to 49 lbs. per acre.

### SOME EFFECTS ON PLANTS

No field moisture determinations were made but some obvious relationships may be noted. The moisture sources of importance are soil water, held by capillary forces throughout the soil, and the ground water, which is of unusual importance here because of the proximity to the surface and its possible salt content. Shallow rooted plants and those growing some distance above the ground water, as on dunes, must depend exclusively on water held in the soil; only an actual examination of the root system will reveal to what extent the deeper rooted plants normally reach the region affected by the ground water. It is quite possible to have a considerable depth of soil containing salt-free soil water overlying brackish groundwater.

The moisture holding capacity of the coarse textured soil is usually assumed to be low but in the surface layers this property is augmented by the content of organic matter. The possible moisture capacity of porous coral has already been suggested. During our stay on Arno, the longest period without rain was not more than a few days and the soil in excavations was never thoroughly dry. Some plants exposed in openings showed temporary wilting during the brief periods of dry sunny weather but recovered overnight. Thus, to judge by mere observation, soil moisture was not a direct factor in plant survival, other than for seedlings, during the June to August period, although it certainly may have



influenced plant growth and competition. Observations in the drier months, however, might well reveal critical soil moisture levels.

In many areas the ground water level is closer to the surface and here, the problem is obviously not water but salt. Although the conductivity data in Table II indicate how well rainfall removes soluble salts from the upper soil layers they do not fairly represent conditions for plant growth on a considerable part of the atoll. Many areas of Shioya sand and loamy sand, and the outer parts of the stony land complex undoubtedly have brackish ground water. Moreover, groundwater salinity often increases during the later winter "dry" season. In this environment salinity, like soil moisture, should be considered a fluctuating soil property for the critical levels that determine plant survival may persist for only brief periods.

The question of "atmospheric salinity" is not considered here although it is fairly obvious that salt spray can influence plants near windward coasts and under unusual storm conditions. As Mr. Cox has pointed out, water samples from the wells of Ine and Arno Islands and from cisterns on Ine have a very low chloride content indicating no appreciable spray contamination on those leeward islands.

Apart from variations due to the seasonal rainfall differences, it is evident that the pattern of groundwater salinity will be affected by permeability of the substrate and by the land width, height, etc. Some sensitive plants may grow almost to the shores where the outward flowing sheets of fresh water prevents movement of salt water inland. Thus breadfruit, which is not considered salt tolerant, has been observed within 35 ft. of a low beach on Ūl-en' Island.

The several considerations mentioned above and the very considerable differences in soil fertility levels suggested by Table II indicate that salinity, important as it is in controlling plant distribution, should not be overstressed.



Thus a plant species or community growing in an area of limesand or Shioya sand may well be exposed to atmospheric and groundwater salinity but these soils are also characterized by low nitrogen, exchange capacity, potassium, etc. Thus the presence of the plant or community elsewhere may suggest low fertility levels, salt content, or both. In a similar vein, the occurrence of certain plants in the island interiors only may be a response to the higher fertility levels there as well as to the salt-free groundwater.

The yellow leaved palms seen on several areas were attributed to excess salinity, largely on the basis of land position, although the possibility of nitrogen deficiency cannot be excluded. A surface soil sample from one such area showed little salinity, a not unexpected finding considering the high rainfall of the period previous to sampling.

Another coconut malady affects an appreciable area in the interior of Arno Island. As already noted, a surface soil sample from a badly affected spot there is unusually low in readily soluble phosphorus. Considering the long occupancy of the land and the relatively high phosphorus demand of the coconut, the possibility of phosphorus deficiency on the area must be considered.

On Mokil, Bentzen (Pacific Science Board CIMA Report, 1949) found an area in the center of each of the three islets composing the atoll on which coconuts were no longer productive. The largest, on Urak Island, is known to have grown breadfruit prior to 1890 when it was cleared and planted to palms. For some years it produced well but yields declined after 1913 and by 1925 it was given up as a commercial venture, although the palms still stand. Inasmuch as Bentzen mentions neither dead trees nor foliar symptoms this condition appears to differ from the Arno syndrome, at least in severity. Both, however, occur on island interiors, cropped to coconuts and in both areas breadfruit trees still grow well. It seems likely that similar maladies will be found on other atolls.

As might be expected, iron deficiency is common on Arno in village areas and clearings or wherever organic matter additions are lacking. Some of the sensitive exotics such as banana, lime and hibiscus become strikingly chlorotic but more or less severe symptoms were noted in fourteen other genera, native and introduced. Experimentally, this condition in the banana was overcome by suitable applications of iron to the leaves but a more practical means is through organic matter additions and mulches. This deficiency may influence plant competition on areas of exposed limesands since Thuarea, Vigna, Tacca, and Centella are at least moderately affected. Under closed forest conditions symptoms are rarely noted.

Mr. Anderson sent a variety of vegetable and flower seeds with our party as a gift to the Arno people. The resulting plantings observed were largely failures either because of cultural or soil difficulties.

A small "garden" was established in Ine Village with the hope of detecting soil factors affecting plant growth. The area had been long cleared and hence presumably did not correspond to similar areas of Arno loamy sand under forest. Onions, radishes, lettuce and tomatoes failed after germination and slight initial growth; pole beans, corn and curcurbits were stunted and their eventual failure appeared certain. Growth was not greatly affected by applications of nitrogen (as ammonium sulphate), potassium or boron. Iron chlorosis masked other symptoms in the tomatoes and curcurbits; the remaining species did not display characteristic phosphorus deficiency symptoms. These considerations together with the prevailing alkalinity and the data of Table II suggest minor elements, other than boron, and possibly phosphorus as the limiting factors for growth.

Coconut-pandanus peat from a taro pit on Arno Island (Profile #24) was potted and sown to tomatoes, lettuce and onions. A photograph by Dr. LaRivers a few weeks later shows that tomatoes and lettuce grew rather well in the peat

fertilized with ammonium sulfate, potassium chloride and crushed phosphate rock, whereas the onions, a salt-sensitive crop, grew much better in the unfertilized material. Wherever peat deposits occur near village areas they could be excavated to surface seed beds and very small garden spots for plants not readily grown otherwise.

On the basis of observations thus far there is no reason why a large number of exotic plants cannot be grown on the atoll soils under garden condition. Alkalinity of the mineral soils will exclude several but the neutral peat can provide a medium for some of these. In the absence of specific information on limiting elements "complete" fertilizers including minor elements seem necessary, or in their stead, heavy applications of organic matter incorporated with the soil or as mulches. Under the conditions of Arno the latter is the only feasible means. In addition to soil factors other cultural requirements, such as adapted varieties, pest control and protection of small seedlings against rain, wind and drying must be considered. Recommendations for the peasant style agriculture of Arno necessarily must be very different from those employed under a more modern agriculture.

## DISTRIBUTION

### Maps

Soil distribution was mapped in detail on the larger islands. In some instances mapping was limited by time or heavy rains and has been supplemented by notes and sketches made on preliminary tours with the local citizens. The attached maps have been prepared by transferring field sheets and notes to base maps enlarged from 1/30,000 aerial photographs. Unfortunately the photographs were not available in time to be of use when most of the field mapping was done and subsequent interpretation from them has been limited by their scale and quality. In some cases the mapping precision is not commensurate with the relatively large scale of the maps.

LEGEND FOR SOIL MAPS

SOIL AND LAND TYPES

Light colored soils of  
narrow lands and shores

Sl Shioya loamy sand  
Sg Shioya gravelly loamy sand  
Ss Shioya sand

Dark soils of the island  
interiors

Al Arno loamy sand  
Ag Arno gravelly loamy sand  
Ll L'angar gravelly sandy loam












Undifferentiated soils and  
land types

P Phosphate rock complex  
Ts Dark shallow soils over  
sandstone  
S.C. Stony land complex

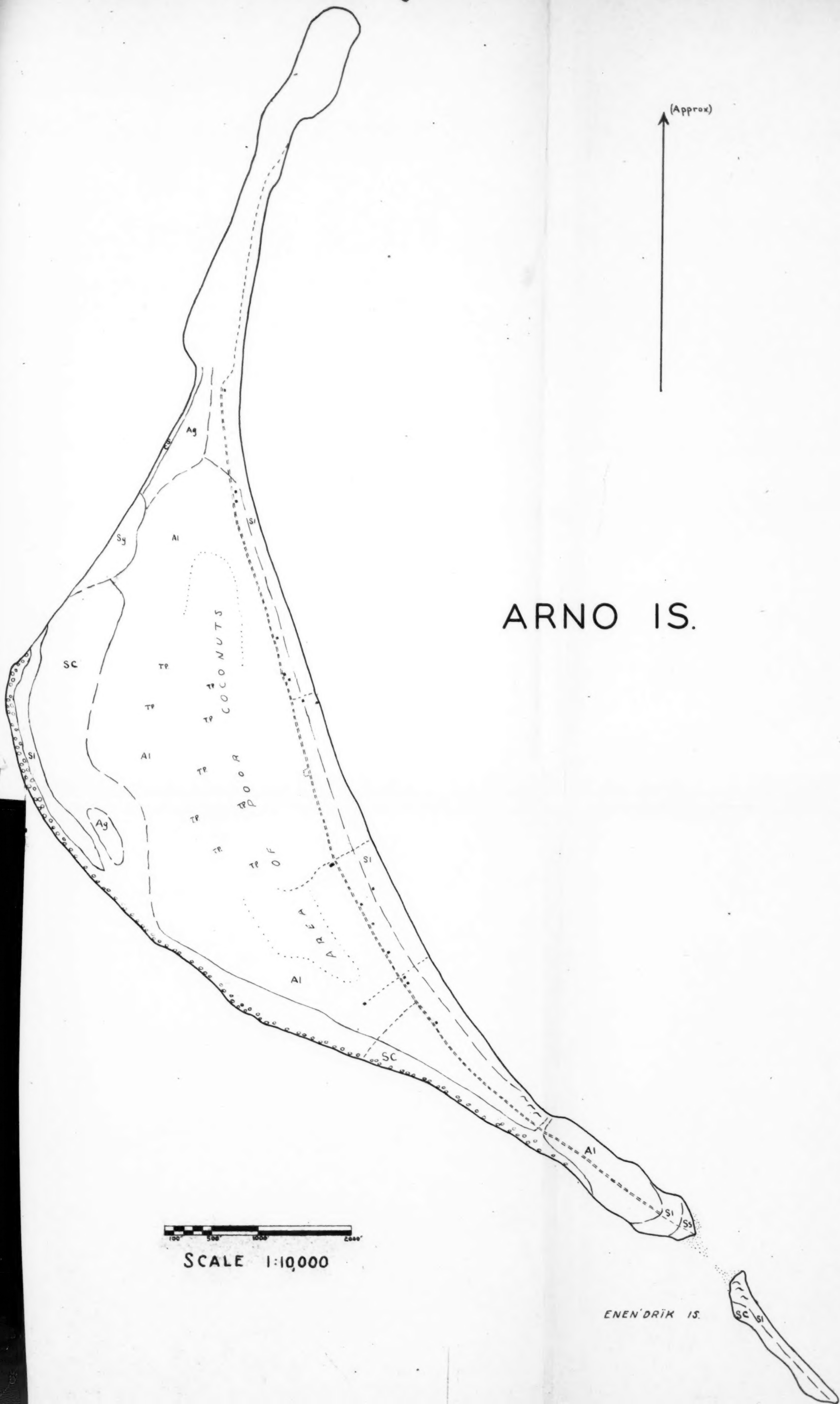
Peats and mucks

Mp Mangrove peat  
Msr Mangrove shallow peat and  
rock complex  
Mm Mangrove muck  
Cp Coconut-pandanus peat

OTHER SYMBOLS

	Limesand shore deposits
	Dune
	Beach rampart and juvenile phases of stony land complex
	Beach sandstone
	Reef rock, conglomerate and sandstones
	Depression
	Erosion escarpment
	Well
	Taro pit area
	Mangroves
	Main walks and trails





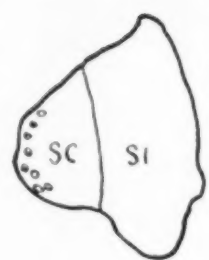
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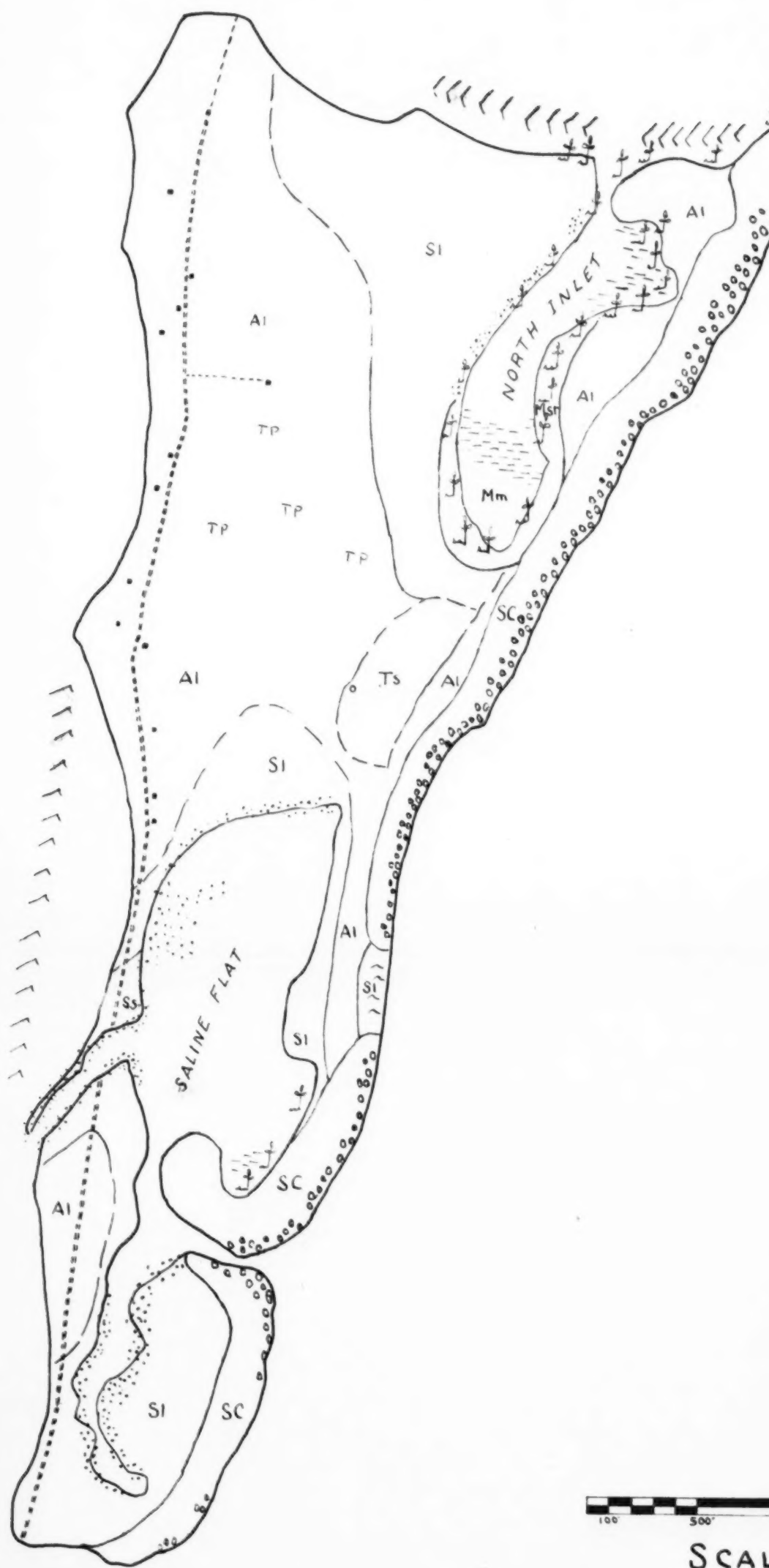
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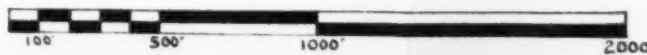
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(Approx)



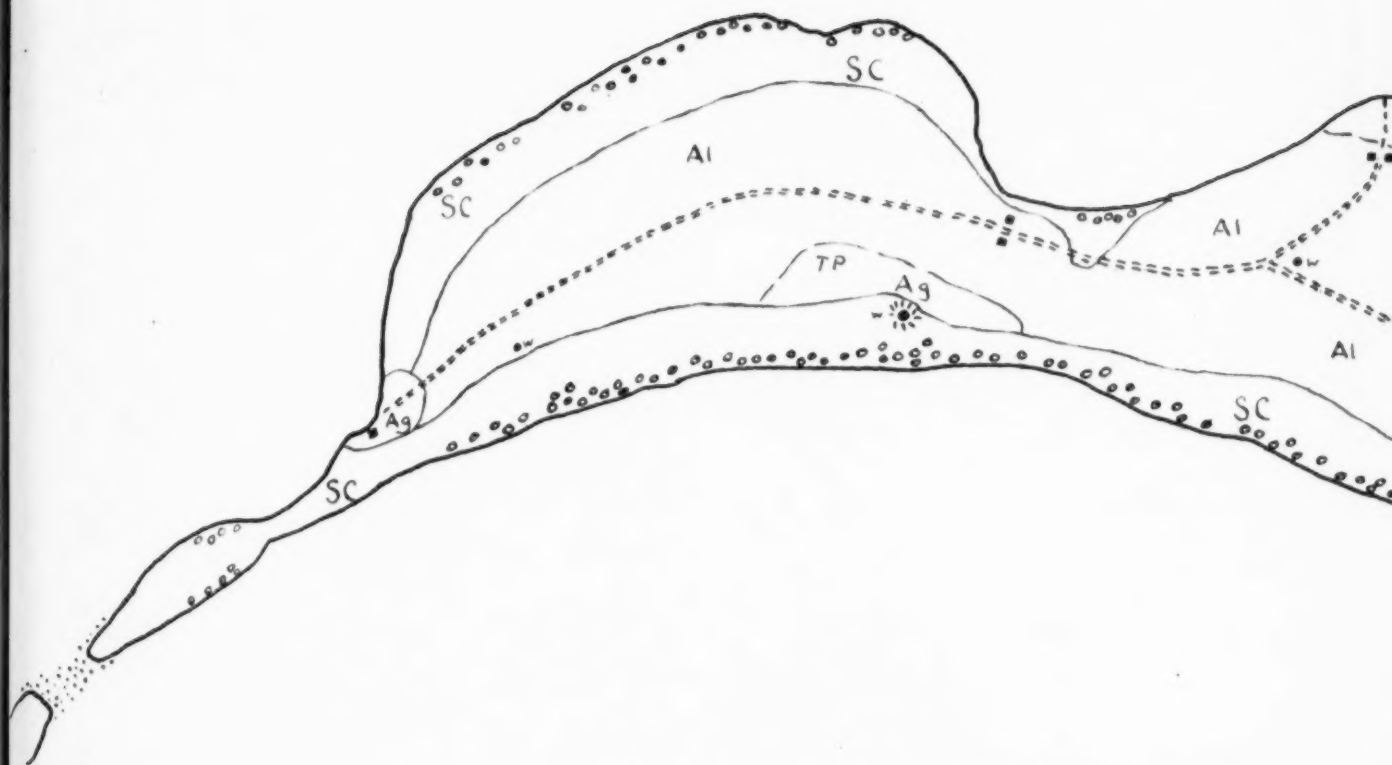
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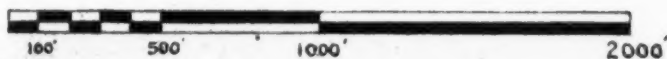
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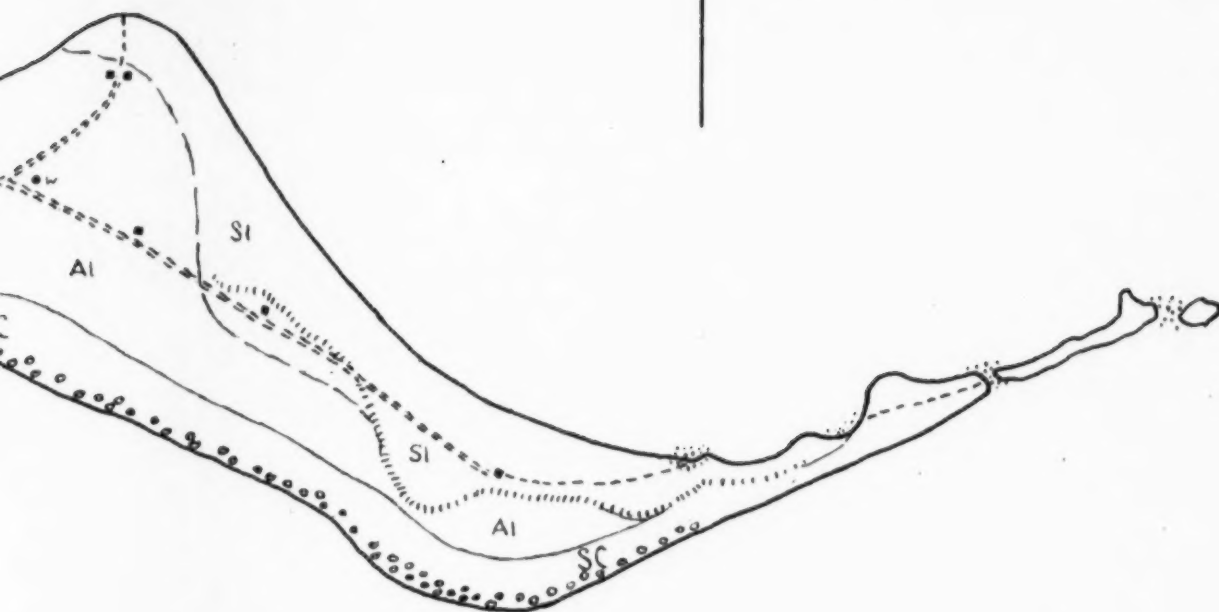


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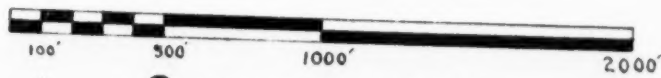
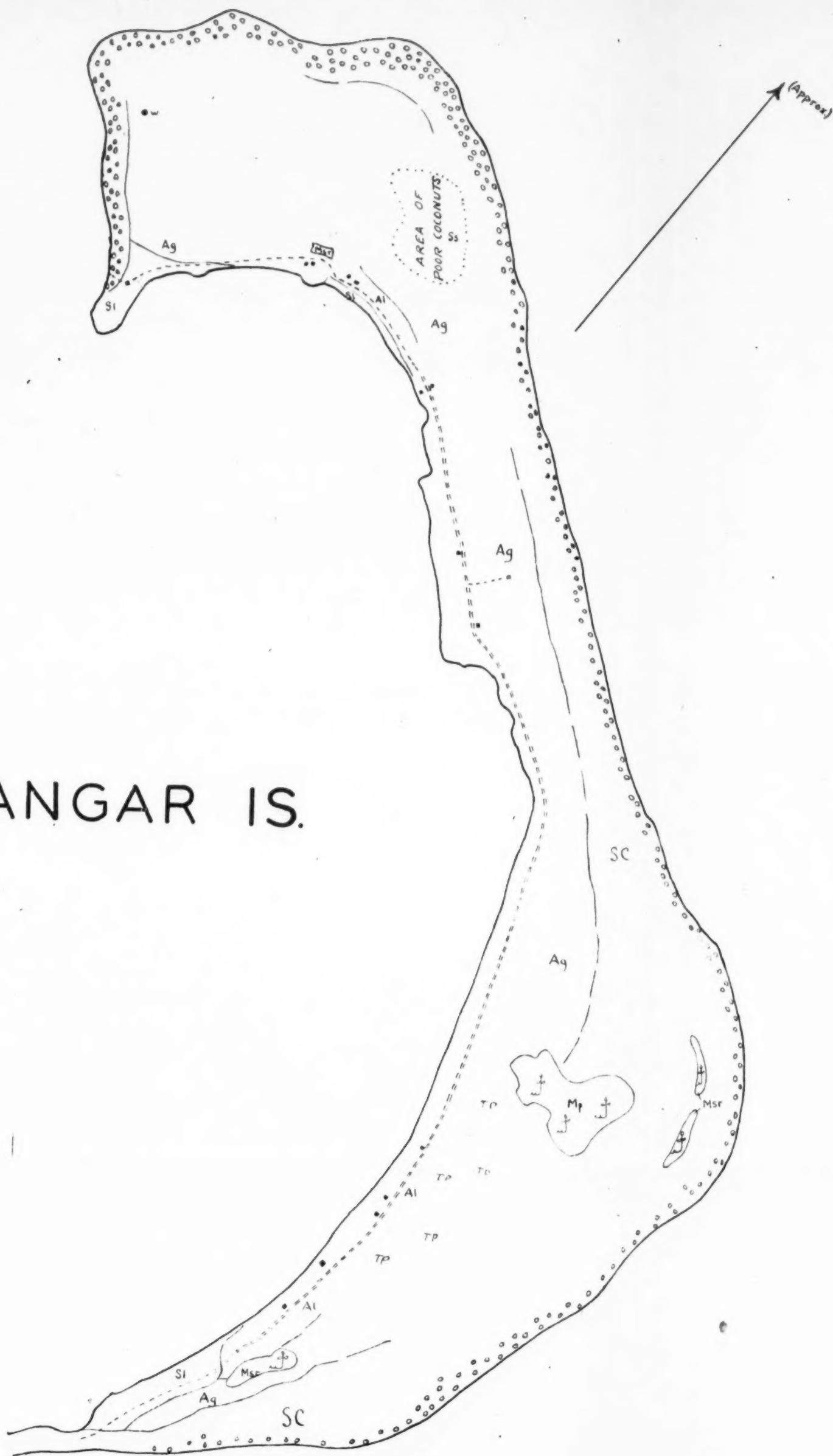


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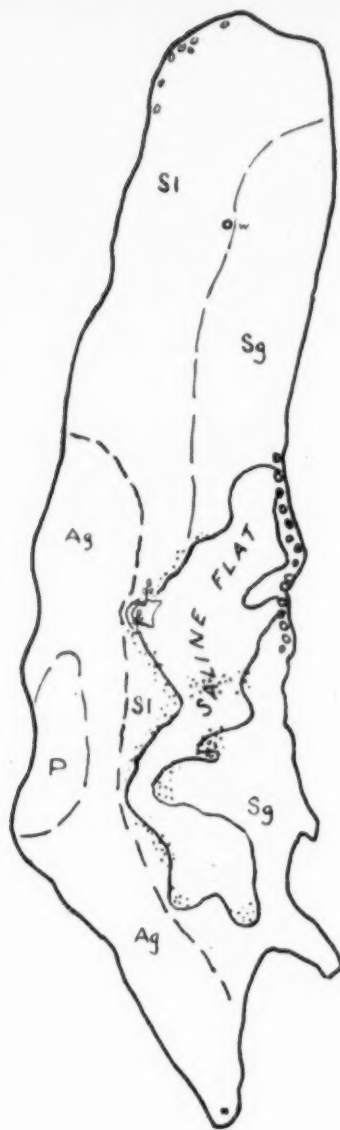
(Approx.)



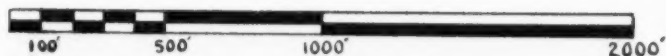
# L'ANGAR IS.



SCALE 1:7500

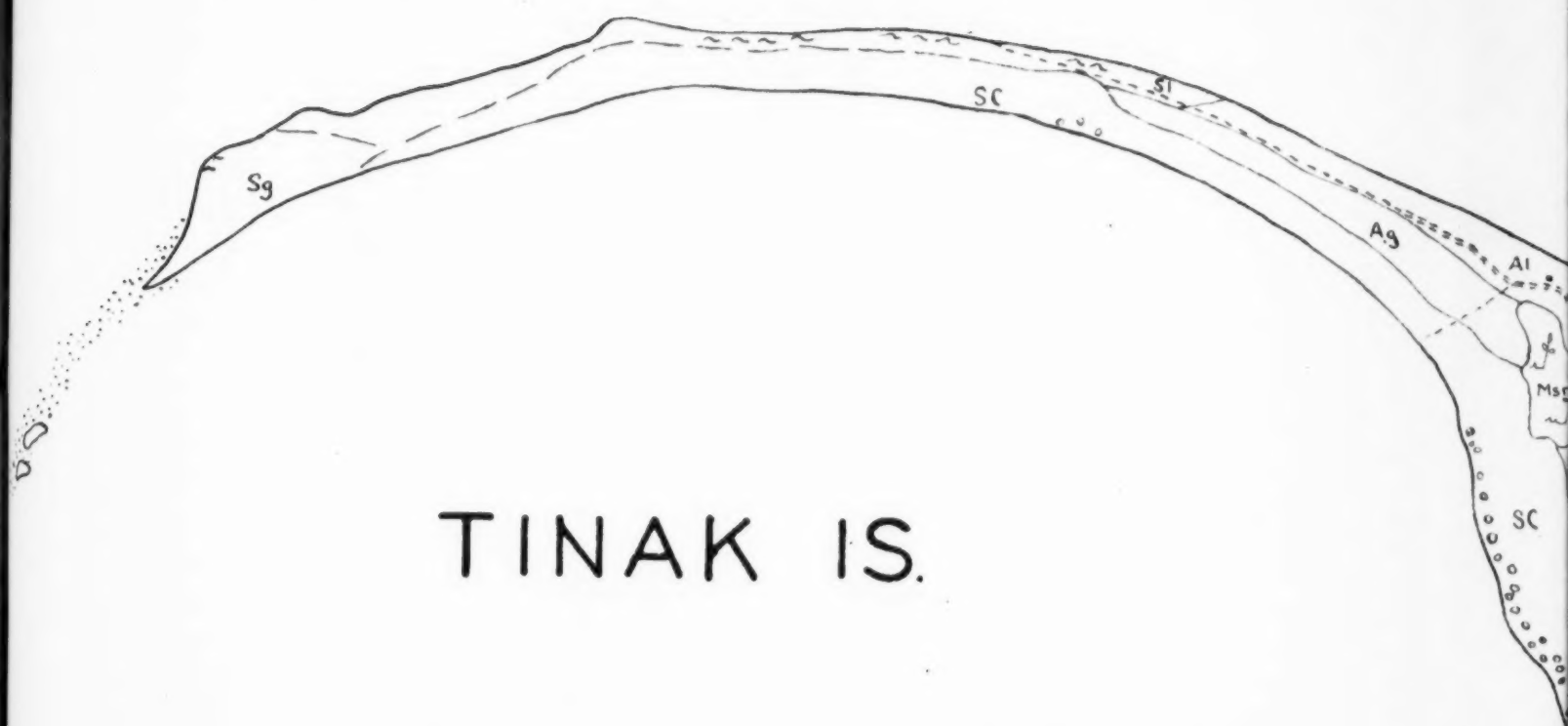


NAMWI IS.

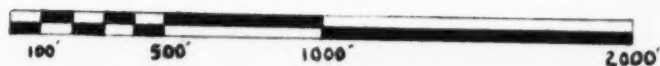


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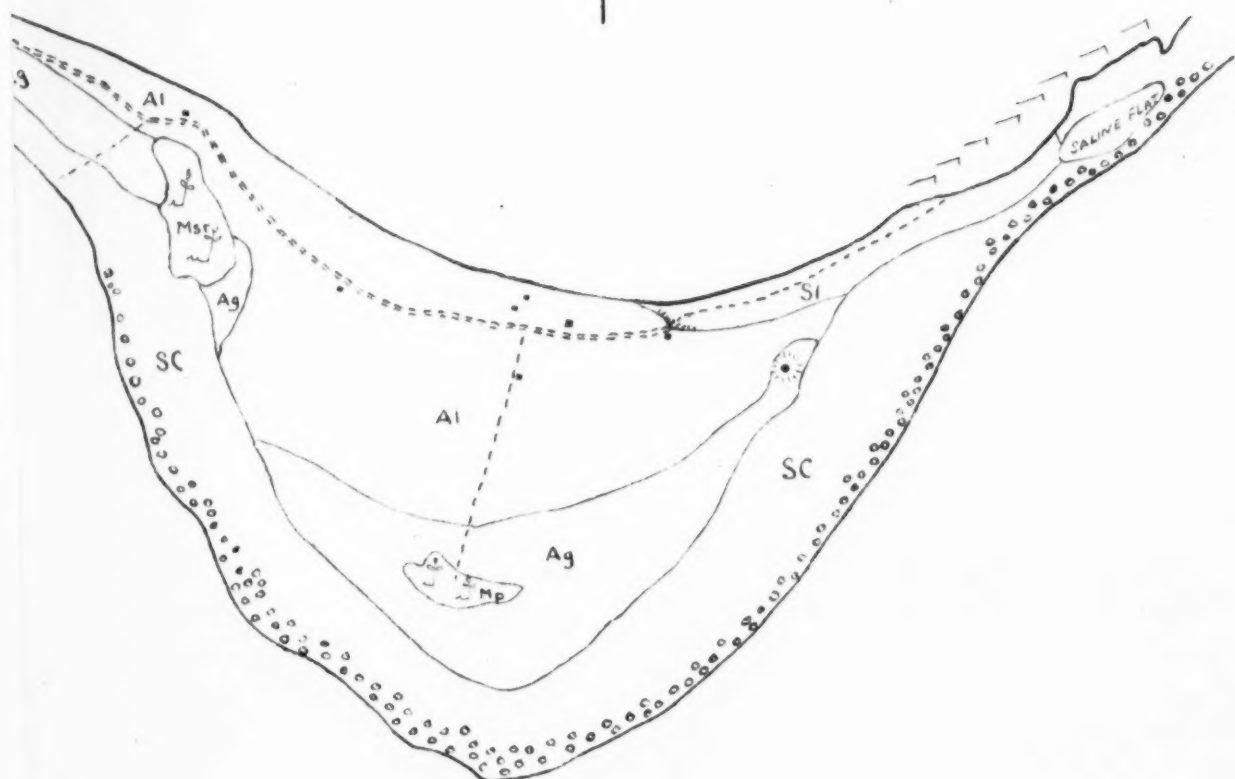


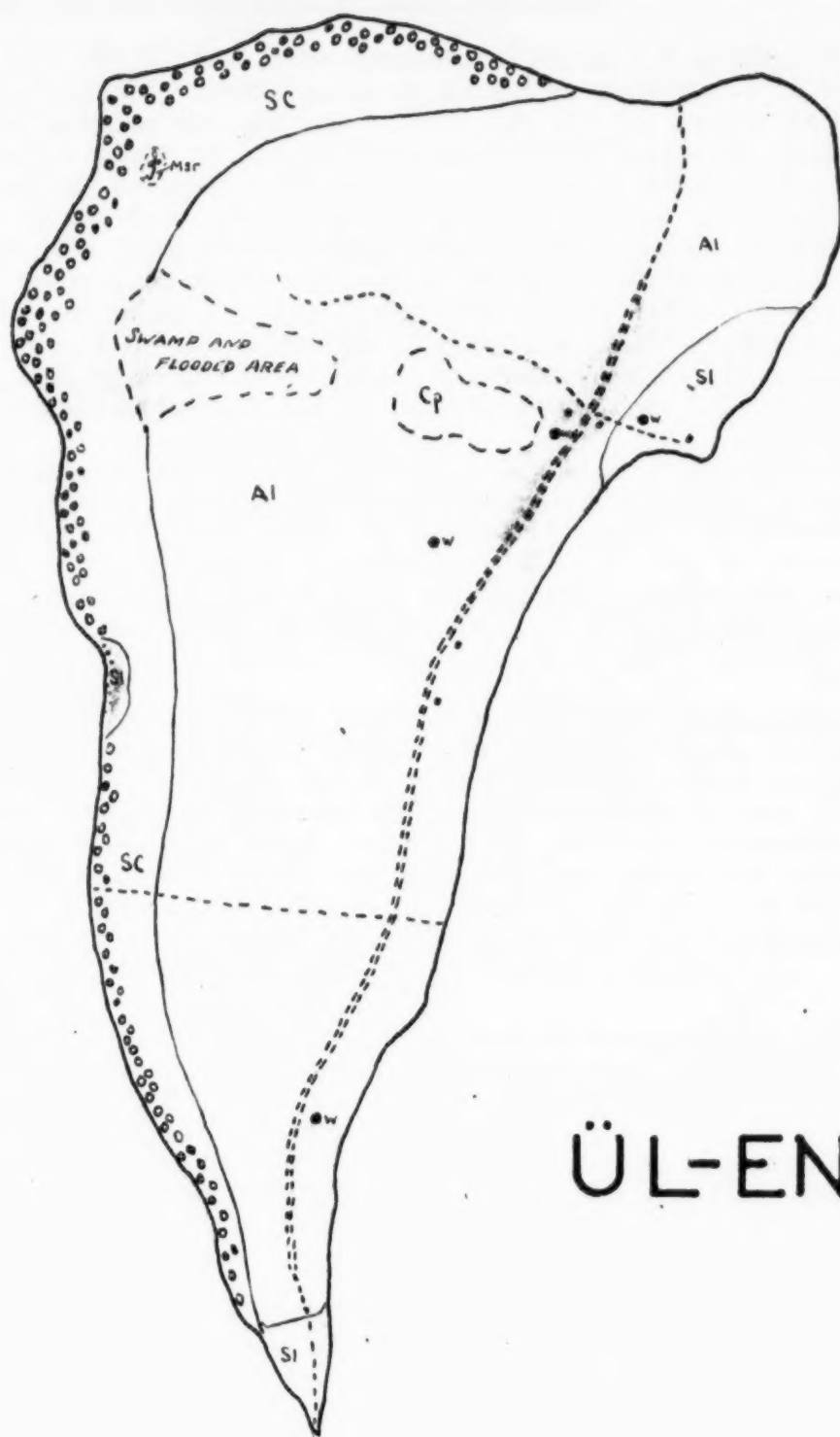
TINAK IS.



SCALE 1:7500

(Approx.)





ÜL-EN' IS.

Notes on Land Conditions to Accompany Maps

ARNO ISLAND - This, the largest island on the atoll, occupies a sharp curve in the reef and extends along it in either direction. A belt of the stony complex margins the sheltered sea coast but its center seems to have been much disturbed. Areas of Shioya loamy sand occur here, the sand sometimes clearly overlying or mixed with the coarse material below. The wide interior is occupied by the Arno loamy sand and its inclusions, and a narrow belt of the Shioya loamy sand fringes the lagoon coast. The boundary of the "poor" coconut zone can be recognized at several points. The groundwater is fresh under most of the island and wells are common near the lagoon coast. A small extent of inland dune occurs on the southeast limb of the island, affording a site for one of the two graveyards on the island. Near this a stony dry channel, apparently swept by storm waters at one time, crosses the island.

The southeast tip of the island is composed of recent sands; a sandspit, covered at high tide, connects with Enen'edrik Island which is said to have been continuous with Arno Island prior to the 1918 typhoon. An indentation in the reef at this point apparently allowed breaching; it also provides the local anchorage. Enen'edrik Island follows the general pattern with rubble on the seaward side and sand along the lagoon but most of the soils appear quite immature.

BIKAREIJ ISLAND - This island may be thought of as composed of five major divisions: (1) A narrow strip of stony land fringes the entire eastern side and extends in an arc to the northeast, forming a long narrow peninsula. (a) A central lowland is composed of the saline interior sand flat in the south, the deep, mangrove-fringed inlet in the north and a low sandstone belt between. (3) A large area of Arno loamy sand makes up the center and western side of the island and (4) a very small area of this type occurs south of the western opening to the interior flat. (5) Less well developed and presumably younger Shioya soils occur between the Arno soils and the lowland.

It is evident that the history of land development has been complex. The off-shore beachrock and the exposure of the Arno soil on the very edge of the western coast suggest that considerable erosion has taken place; the southern occurrence of this soil may well have once been part of a larger area. Away from the beach, the southern part of the stony complex appears older than the northern arc and is fringed with the Arno soils. The western side of the peninsula rests on sandstone which affords footing for a few stunted *Bruguiera* on its corroded surface.

Limesand banks are now forming in places along the sides of the interior sand flat and an appreciable area of younger soils surround the flat, suggesting centripetal filling. A zone of soils intermediate in character between the Arno and Shioya loamy sand occurs north of the flat. Similar soils grading into the Shioya series occupy a large sector west and northwest of the north inlet. Where this sector borders the inlet is a narrow belt of recent sand deposits; here and for some little distance west the burrowing of crabs has disrupted any profile formation. Between the inlet and the southern flat is the low area described as having dark soil shallow over sandstone. It seems probable that this sandstone is continuous with that of the inlet exposure and the rock underlying the southern flat.

The small northwest island of Bikonele consists of Shioya soils and stony soils equivalent in age. A considerable quantity of pumice "pebbles" were found on the soil surface inland but their total mass is negligible.

**KILANGE ISLAND** - The western half of the island occupies an unique position on a reef flat that separates two narrow lagoons. Although somewhat protected by the broad reef to the north it has stony belts on both sides of the land. The northern belt ends near the lagoons but the southern one is continuous along the seaward coast. Most of the remainder of the island consists of Arno loamy sand and gravelly loamy sand, but an irregular belt of Shioya soils occurs along the northeast coast. Although not precisely located, its inland boundary coincides in part with a low (3 to 4 ft.) escarpment that merges with the seaward rampart as the land narrows to the east. Presumably the escarpment and the younger soils are the consequence of the 1905 typhoon.

Only three fresh water wells were reported on this island although many more could and may exist. One near the fork in the main trail is some 5-1/2 ft. deep in beach sands and was dry at mid-tide. Another near the western end of the wide land is "usually fresh." The third well is at the bottom of a large deep (8 to 10 ft.) depression at the inner edge of the rampart. A reported jon swamp proved to be but a small mucky depression with two *Bruguiera* trees.

**L'ANGAR ISLAND** - The seaward coast of L'angar is fully exposed to the northeast trades and it is fringed with a high coarse rampart for its full length. Vegetation rises as a wedge with the flattened *Scaevola* at the rampart edge becoming a taller *Scaevola-Messerschmidia* scrub which, in turn, mixes with and gives way to pandanus trees. The tall pandanus, with occasional broadleaved trees, taper upward to the palms inland, the whole consisting an excellent windbreak.

For convenience the island may be considered in three sectors although the soils in all are similar, for the most part very gravelly or stony with continuous sands near the lagoon coast only. The wide northern sector is in densely overgrown coconut groves and secondary forest, and the features inland were not well located. Clearing of the groves is in progress but at no rapid rate. A tangle of *Clerodendrum* on moist soils west of the lagoon path provided the only truly impenetrable thicket encountered on the atoll. The phosphate deposit and area of "L'angar gravelly sandy loam" have been described. An appreciable area of Shioya sand (Profile #23), mapped from the aerial photos, is associated with a coconut malady that has "always" been present. Seedlings are yellow and the mature trees soon cease bearing, become sparsely leaved and die. A well 250 ft. inland from the rampart is reputedly the only fresh water well on the island. The bottom, some 9 ft. below the surface, was dry when seen because of sand fallen from the sides.

Inside the rampart the middle sector is made up of Arno gravelly loamy sand with a fringe of sand along the lagoon.

The large southeast sector contains several taro pits lying back of a broad dune ridge area of Arno loamy sand. The taro is said to have been killed when the pits were last flooded by salt water during the 1918 typhoon. Waves of the 1905 typhoon swept over the southern end of the island and the boundary of wave action, as recalled by the people, corresponds with that of the younger



Shioya soils. The stony complex occupies a large fraction of the sector and the remainder seems to correspond with the Arno gravelly loamy sand. This sector also contains three mangrove swamps; the easterly has a brackish pool in exposed beachrock which is another of the local marvels.

NAMWI ISLAND - Like Ul-en' Island, Namwi was seen only in a wandering tour with our hosts of the day. The island consists of four divisions: (1) About three-fourths of the western half is older land and contains the phosphate rock. (2) East of this is an extensive saline flat which is now closed off from the sea or nearly so by (3) a rampart and young gravelly land along the south and east. (4) The northern quarter or third of the island also has younger soils, chiefly Shioya gravelly sand and loamy sand.

The older land may once have extended further to the west for the marginal rampart is very narrow and highly weathered. The phosphate deposit was roughly estimated to be at least an acre in extent; at one point where the rock is exposed along the coast it shallowly overlies unaltered coral conglomerate. As noted, the dark phosphatic soil, "Namwi gravelly loamy sand", adjacent to the phosphate deposit was not distinguished from the surrounding Arno gravelly loamy sand.

The interior flat is said to be flooded 5 or 6 inches deep by high water at the bimonthly spring tides. Only the lowest parts are barren; the slight rises have a sparse growth of small *Scaevola*, *Messerschmidia* and very yellow sprouting coconuts. Along the margin are two small saline pools, the larger fringed with *Sonneratia* and *Bruguiera*.

Approximately in the center of the northern division is a shallow fresh water well. The young planted coconuts north of the well exhibit some yellowing but no severe symptoms.

TINAK ISLAND - The wide land coincides with a marked convexity of the reef. The coastal stony belt is markedly higher than the expanse of Arno soils which extend from it almost to the lagoon beach. A low dune ridge now fronts the lagoon and a cross-section from the rampart to the lagoon would show a slightly undulating surface, suggesting a series of old beach lines or ridges.

Two mangrove swamps occupy depressions. The only existing well is in an unusual natural basin, perhaps 100 ft. across, and some 8 to 9 ft. below the surrounding land surface. The "well" is a pool about 5 x 9 ft. and 3 ft. deep in reef rock or beach conglomerate. It is never dry and at high tide the fresh water rises nearly to the rock surface. Within the depression and perhaps 2 feet higher than the rim of the well is a patch of shallow mucky soil that serves as a hog wallow; water seeps into this at high tide. Elsewhere on the island two former wells are now filled.

The Shioya soils which fringe part of the lagoon coast come to border the rampart at the narrow neck of land where Tinak Island passes into Enëraen Island. An included low area of Shioya sand in young palms was flooded by high water in 1947. Further to the northeast is a small inland flat cut off between land that survived the 1905 typhoon and a rebuilt rampart.

For part of its length the gooseneck peninsula extending to the southwest shares the soil pattern of the wide island. The lower two-thirds, however, has been washed over and the soils are of younger age.

ŪL-EN' ISLAND - This island consists of a belt of stony land along the seaward coast with lagoon sands, chiefly mapped as Arno loamy sand, making up most of the remainder. The northwest tip of the island, which borders the channel separating the next islet, shows numerous narrow overlapping layers of beachrock that mark successive minor advances and now a minor retreat. Thus this edge has been relatively stable. The southeast point of the easterly bulge, however, is composed of younger soils and people recognize that it is building out, and further south the beach is said to have eroded about 12 ft. in the past 30 years. The extreme southern tip is again composed of younger sand.

The unique swampy areas were seen in a circuitous route and hence are not precisely located. The area of coconut-pandanus peat has been described. Nearby, but apparently separated from that swamp, is another containing a narrow pool, some 10 x 50 ft., surrounded by peat about 16 inches deep and mucky sands; the water is sufficiently fresh that soap can be used. West of the pool is a low area flooded at high tide; the sandy soil has a darkened surface crust but no profile development. Adjacent to this area and extending towards the higher rampart, is an immature gravelly soil with "yellow" coconuts. The syndrome resembles that observed on L'angar Island, although less severe, and suggests soil salinity. Further north a small mangrove swamp occurs in a depression in the rampart.

Four of the five wells of the island are located on the map. All are in sand near the lagoon shore and are said to be never dry or salty. Oddly, the one closest to the beach, 150 ft., apparently has the least tidal fluctuation.

APPENDIX A

SCIENTIFIC NAMES OF PLANTS REFERRED TO BY GENUS.

(According to lists kindly supplied by R. Fosberg and D. Anderson.)

Allophyllus timorensis	Nephrolepis acutifolia
Artocarpus altilis	Ochrosia oppositifolia
Asplenium nidus	Osplismenus compositus
Bruguiera conjugata	
Calophyllum inophyllum	Pandanus tectorius
Canavalia microcarpa	Pemphis acidula
" sericea	Pipturus argenteus
Centella asiatica	Pisonia grandis
Clerodendrum inerme	Polypodium scolopendria
Colocasia esculenta	Premna integrifolia
Cordia subcordata	
Cyrtosperma chamissonis	Scaevola frutescens
	Sonneratia caseolaris
	Suriana maritima
Eleusine indica	
Fimbristylis cymosa	Tacca leontopetaloides
Guettarda speciosa	Terminalia samoensis
Intsia bijuga	Thuarea involuta
Ixora casei	Triumfetta procumbens
Lepturus repens	Vigna marina
Lumnitzera littorea	
	Wedelia biflora
Messerschmidia (Tournefortia)	
argentea	
Morinda citrifolia	

APPENDIX B

ABRIDGED DESCRIPTIONS OF PROFILES SAMPLED FOR CHEMICAL ANALYSES (Table II)  
(See also descriptions of numbered profiles in text.)

Profile #23 - Arno loamy sand. From area of poor coconuts, interior of Arno Island:

- 0 - 6" Black (10 YR 2/1) granular organic loamy sand or sandy loam, heavily flecked with limesand particles.
- 6 - 8" Rapid transition from very dark gray to light gray limesands.
- 8 - 48"+ Single grained loamy sand containing some coarser forams, very pale brown (10 YR 8/3) becoming pinkish white (7.5 YR 9/2) at depth. Soil moist at 30-36" but no water encountered.

Profile #29 - Arno loamy sand. Wide portion of Jab'u (Ine Is.).

Surface Two-thirds covered with decomposing breadfruit and Guettarda leaves.

- 0 - 8" Very dark gray (10 YR 3/1), highly organic, somewhat plastic sandy loam or loamy sand containing some gravel and small stones. Earthworms present.
- 8 - 12" Transitional.
- 12 - 36"+ Single grained loamy coarse sand, pinkish white (7.5 YR 9/2) becoming white (5 YR 9/1), containing some gravel and small stones.

Profile #6 - Arno gravelly loamy sand. Ine Island, southeast of village.

- 0 - 1/4" Incomplete cover of pandanus and coconut leaflets, etc.
- 0 - 15" Very dark gray (10 YR 3/1 or 2.5/1), coarsely granular, highly organic gravelly loam becoming sandier near the bottom. Earthworms abundant. Much of the large content of gravel is rotten and can be crumbled.
- 15 - 18" Transitional.
- 18 - 56"+ Pinkish white (7.5 YR 8/2), single grained limesands containing some gravel. Slight localized cementation around coconut root at 36" but no general cementation.

Profile #4 - Moderately well drained associate of the Arno series developed over a buried profile. Ine Island, southeast of village.

- 0 - 8-12" Very gravelly, dark gray (10 YR 4/1), somewhat plastic organic loam flecked with light sand grains. Earthworms abundant. Gradually changing to



8-12 - 16-20" Heterogenous transitional zone consisting of mixed limesand or a pure foram sand flecked with black from decaying coconut roots and with tongues of organic matter penetrating from above. Earthworms still abundant in this horizon.

16-20 - 28" White (5 YR 8/1) loamy sand.

28 - 35" Transitional. The loamy sand becoming grayer and slightly cemented.

35 - 58"+ Gray (10 YR 5/1) loamy sand heavily flecked with white sand grains. Many roots occur in this horizon and large stones are found near the bottom of the profile. Groundwater level at 58" near the high tide peak.

Profile #14 - Shioya sand. Area of poor coconuts in interior of L'angar Island.

0 - 10" Pinkish gray (7.5 YR 7/2) single grained loamy sand.

10 - 36"+ Pinkish white beachsand appearing quite fresh and unweathered.

Profile #27 - Shioya sand with surface deposit. Narrow land revegetated after the 1918 typhoon, Jab'u (Ine Is.).

44" - 0 Overburden of sand washed from dune above. White (10 YR 8/1) with some varicolored fragments, single-grained, already well penetrated by small coconut roots.

0 - 6" Light gray (7.5 YR 7/1) limesand mixed with some coarse gravel, densely penetrated by coconut roots. No worms present. Becoming somewhat lighter and coarser without the gravel at the bottom of the horizon.

6 - 70"+ Gradual transition from above to pinkish white (7.5 YR 9/2) limesand somewhat spotted with decaying coconut roots in the surface six inches and locally below. Coconut roots common to at least 36". Groundwater level at 42 inches after heavy rains.

Profile #18 - Mangrove peat. Tinak Island.

0 - 8" Fibrous woody peat from Bruguiera. Dark reddish brown (5 YR 2/2) crumbs mixed with a large mass of small rootlets. Fine coral fragments present.

8 - 16" Similar but with fewer roots and more coral fragments. Groundwater at 15".

Profile #26 - Coconut-pandanus peat. Ūl-en' Island.

0 - 26" Very fibrous woody peat consisting of dark organic crumbs mixed with a mass of root fragments, many of them hollow. Water level at 8" below surface when sampled, 3-8" above the next morning after heavy rains.



## APPENDIX C

### EFFECTS OF MANGROVE MUCK FROM BIKAREIJ ISLAND

The following is an account of the reputed effect of the muck on human skin as given by several people on this island:

At high water during the spring tides, schools of a desirable fish, "Beleo", enter the inlet and can be prevented from leaving as the water falls by a stone weir. On special occasions, formerly designated by the King, this area is "fished." By custom the entire village is required to go as a group. At low water the men wade about in the muck, churning it until the mud "soaks up" the surface layer of water. Thereupon the fish stick their heads out of the ooze and are caught or speared, the catch being very large, "more than a thousand" by Marshallese arithmetic.

If a man remains in this mud for as much as "three hours" his body below the point of immersion will swell greatly. For four days he will suffer headache, fever, loss of appetite, etc. On the fifth day these symptoms subside and the small blisters on the skin, resembling those of heat rash, break. The old skin can be peeled off "like a glove," exposing new epidermis beneath. An exposure of two hours has some effect so the general rule has been to limit exposure to one hour. (All time intervals as given by Kieotak.)

The details of this malady and its occurrence were clear and consistent in the accounts given by different people. A Japanese who visited the island to investigate this phenomena gave no explanation and only suggested swabbing with Lysol solution after exposure. It is clear that prolonged exposure is required for injury and that this is superficial. The cause can only be conjectured but there are two likely agents: (1) sulphites or sulphides in the alkaline slurry and (2) (suggested by Dr. Steven Kliman) tannins derived from the mangroves.

In addition to its external effects the mud is reputedly toxic if it accidentally enters the mouth when one is tired. A small amount (= "one finger joint") is sufficient to cause dizziness and unconsciousness. Two persons are said to have been lost in the mud after having been so overcome. Wading waist deep in the viscous slurry is a very fatiguing task, however, and it is possible that these latter effects might be due to over exertion.

## APPENDIX D

### DISPOSITION OF PLANT COLLECTIONS

Since Mr. Donald Anderson had collected the higher plants of the atoll just previous to the visit of our party, my collection of these was largely for orientation. Fertile material of Dryopteris goggilodus and Oplismenus compositus and two additional plants, Nasturtium sarmentosum and Eleocharis geniculata believed not collected by Anderson have been placed with his collection; the remainder of my partial collection will go to the herbarium of the Botany Department and the Bailey Hortorium at Cornell.

The few lichens were sent to Dr. Joyce H. Jones of the University of Michigan Herbarium who has identified them as follows:

- 1044 - *Pannaria mariana* (Fries) Müll. Arg.
- 1065 - *Physcia picta* (Sw.) Nyl.
- 1081 - no spores found
- 1119 - gray wider lobes - *Coccocarpia cronia* var. *isidiosa* (Müll. Agr.) Vainio, greenish gray - *Physcia integrata* var. *sorediosa* Vainio
- 1120 - *Parmelia corraloidea* (Key. & Flot.) Vainio
- 1145 - crustose - no spores found
- 1150 - *Physcia picta* (Sw.) Nyl.  
a, b and c. are the same
- 1151 - found no fruiting bodies
- 1152 - *Coccocarpia cronia* var. *isidiosa* (Müll. Arg.) Vainio
- 1157 - *Leptogium* sp. - found no fruiting bodies.

A few collections of terrestrial algae were sent to Dr. R. H. Thompson, Department of Botany, University of Kansas. A number of fungi were turned over to Dr. Clark Rogersen, Department of Botany and Plant Pathology who has sent the Basidiomycetes to Dr. Don Rogers of N. Y. Botanical Garden. The mosses and hepatics were identified by Professor A. L. Andrews of Cornell.

MOSSES AND HEPATICS FROM ARNO ATOLL, MARSHALL IS., 1950

Mosses

- |         |   |
|---------|---|
| 1039    | <i>Calymperes thyridioides</i> Broth.                   |
| 1041(a) | <i>Ptychocoleus pycnocladus</i> (Tayl.) Steph.          |
| 1042    | <i>Ectropothecium sandwichense</i> (Hook. & Arn.) Mitt. |
| 1043    | <i>Leucophanes smaragdinum</i> (Mitt.) Par.             |
| 1115    | <i>Trichosteleum hamatum</i> (Dozy & Molk.) Jaeg.       |
| 1116    | <i>Ectropothecium sandwichense</i> (Hook. & Arn.) Mitt. |
| 1154(a) | <i>Meiothecium papillosum</i> (Broth.) Broth.           |

Hepatics

- |         |  |
|---------|--|
| 1040    | <i>Riccardia fuscescens</i> (Steph.) _____ ?           |
| 1041(b) | <i>Lejeunea</i> sp., (Subgenus <i>Cheilolejeunea</i> ) |
| 1154(b) | <i>Lopholejeunea subfusca</i> (Nees) Steph.            |
| 1155(a) | <i>Drepanolejeunea Riddleana</i> Steph.                |
| 1155(b) | <i>Lejeunea</i> sp.                                    |

The above workers will retain material for their own herbaria and in accordance with the National Academy of Science agreement duplicate collections will be sent to the National Museum. Any additional material will go to the Bishop Museum.

THE SOILS AND AGRICULTURE OF ARNO  
ATOLL, MARSHALL ISLANDS.

II. AGRICULTURE

# C O N T E N T S

The General Agricultural Scene	1
Physical Setting	1
Agriculture	2
Plants and their Utilization	3
Coconut, "Ni"	3
Culture	3
Copra Production	5
Uses as Food	7
Other Uses	9
Factors Affecting Production	10
Breadfruit, "Ma"	12
Culture	12
Uses as Food	14
Other Uses	15
Factors Affecting Production	15
Pandanus, "Böp"	17
Culture	17
Uses as Food	18
Other Uses	19
Factors Affecting Production	20
Taro and Other Araceous Plants	20
Colocasia	20
Cyrtosperma: Culture	20
Uses as Food	22
Cyrtosperma: Factors Affecting Growth	22
Alocasia	23
Polynesian Arrowroot, "Makmök"	24
Banana	25
Culture	26
Use	27
Factors Affecting Production	27
Papaya and Lime	28
Other Introduced Food Plants	29
Other Introduced Plants	30
Indigenous Plants of Value	31
Livestock	32
Poultry	32
Swine	34
Wood Supplies and Requirements	35
Forest Situations	35
Species and Uses	37
Construction Requirements	38
Future Measures	39
Food Supplies and Nutrition	40
Summary of the Agricultural Situation	43



To the ecologically minded the low islands appear as a unique habitat for man, an environment not harsh but marked by lack of diversity and, in many respects, by monotony. Here is a climate so equable that the average temperature for any month departs not more than a degree from the yearly mean, a land restricted in size and relief, dominated by the sea, and made up almost entirely of one material -- calcium carbonate. Upon this are soils uniformly calcareous and differing chiefly in texture and degree of maturity. Distance, soils and the sea salt have sharply restricted the number of land dwelling plants and animals, and so limited man's choice of foods and materials.

#### THE GENERAL AGRICULTURAL SCENE

##### Physical Setting

The climate, hydrology and soils of Arno Atoll are described in other reports but may be summarized as background thus: The mean annual temperature presumably is almost identical with that of Jaluit, that is 80° F., with monthly means deviating about  $\pm 1^\circ$ . Rainfall is some 120 inches, possibly higher, rather well distributed but with a tendency for a dry period between January and March. High humidity and high degree of cloud coverage augments the effects of rainfall, whereas the more or less constant winds, coarse textured soils and short term (e.g. one week) periods of dry weather sometimes lead to a moisture stress in plants. Since the ground water commonly occurs three to six feet below the soil surface its salinity is a major factor controlling the distribution of deep rooted vegetation. Shallow rooted plants, however, draw upon the rainwater held in the soil.

### Agriculture

Like other aspects of the Atoll, the agriculture is marked by simplicity. There is no sharp separation between agriculture and non-agricultural plants and, to Western eyes, culture is a somewhat casual affair at best. At first glance the coconut dominates the agriculture as it does the landscape but there are other components to both. A shrub belt lines the seaward shores and takes possession of lands too salty or too new for other vegetation. In the interiors of the wider islands are breadfruit, sometimes in groves or often scattered, with a variety of other plants beneath. In this zone, too, are the old excavations made to provide suitable growing conditions for taro for here the groundwater is largely free of salt. Mixed with the breadfruit are tall coconut palms and these form extensive groves around the zone and along the narrow lands adjoining.

Various writers have described the agriculture of the atolls as consisting of tree and root crops -- coconuts, breadfruit, pandanus and bananas, together with taro and Polynesian arrowroot. In a general sense this is true but on Arno the taro has lost most of its former importance. Sweet potatoes are a rarity and other tropical root crops absent. Further, poultry and, to a limited extent, pigs are part of the casual husbandry. Fish and seafoods provide the protein the land does not. Over the years copra traders, missionaries and former German and Japanese residents have introduced a large number of plants but of these the weeds and ornamentals have been most persistent.

Although the introduced plants have not greatly influenced the basic agriculture, the prolonged emphasis on copra production has. Well before the beginning of "German times," traders made copra a commodity of value; under German and, later, Japanese administrations people were "encouraged"

to continually increase the area of coconuts. Ultimately this extension eliminated the native forest that once covered the unused lands and reduced the number of breadfruit and pandanus.

Other changes occurred during the early period of missionary activity and German contact: Old men now living say that the population diminished greatly then, although this is unsupported by other evidence. Certainly a population shift occurred, with people moving to lagoon shore and abandoning the less desirable house sites on the seaside and island center. The culture of taro, once a staple, diminished, very probably because the introduced hogs became very abundant and devastated the taro pits. The copra brought goods from the outside world and these gradually became essentials. Under the influence of trade, outside authority, and religion the established culture changed, and the transition from old ways to new is still in progress.

#### PLANTS AND THEIR UTILIZATION

##### Coconut, "Ni"

Although waving palms are almost synonymous with atolls, the extensive coconut groves are as artificial as orchards and will not persist without man's care. Under the influence of the copra trade, "native" vegetation gave way to palm plantations wherever growth conditions were suitable; much of this occurred within the memory of men still living.

##### Culture

There has been little varietal selection and most of the palms bear nuts of mediocre size, although the people recognize differences such as nut color and edibility of the mature meat. Under Japanese instruction "diseased" trees -- presumably scale infested -- were cut, possibly reducing the number of susceptibles. A large fruited coconut has been introduced and is found in small numbers but there seems to be no concerted attempt to

increase this variety.

The culture of the coconut is simple but continuous. Planting consists of removing a square of sod or the loose rocks if necessary and placing the sprouting nut. The large amount of stored material in the nut gives rise to a large seedling and even in deep rubble the roots reach down to establish contact with soil moisture. Competing vegetation is kept down and trees are said to reach bearing age in about five years. Present planting is largely a matter of filling in occasional openings but in several areas the palms are over-mature and replacements should be considered. The coconut, of course, tolerates considerable salt, possibly even benefiting from it, and palms have been planted over the entire salinity range, from the wide island interiors to areas too salty for normal growth.

The groves require continual weeding for a large variety of woody species soon spring up beneath the palms and if unchecked compete with them, as well as making nut gathering almost impossible. Near the coasts and on narrow lands *Scaevola*, *Messerschmidia*, *Guettarda*, *Ochrosia* and "wild" *pandanus* are aggressive invaders whereas inland *Allophyllus*, *Morinda*, *Pipturus*, *Pandanus*, as well as some of the above fill in beneath the palms. In plantations left unharvested, particularly those of the interiors, sprouting nuts soon make a solid mass of undergrowth. Periodic cutting is the only means of controlling this vegetation. Once well cleared an area can readily be maintained but when abandoned for a long period, as many plantations were in the later stages of the war, strenuous efforts are required. Often the coarse herbaceous vegetation, such as *Wedelia*, is also cleared. Usually the brush is burned, together with the fallen fronds. Sometimes the piles for burning are placed over stumps or against undesirable trees so fire supplements the machete. Quite frequently, however, palms and



other useful trees are scarred by careless burning. When the emptied husks and fallen fronds are heaped together burning is often incomplete and the lightly charred heaps decay naturally. Except for these, the signs of fire disappear rapidly; woody and herbaceous sprouts soon mantle the soil and the profound effects of the clearing may go largely unappreciated by the casual observer.

### Copra Production

The major export product, of course, is copra. According to Lajiblok, who has largely transported the crop, the monthly production for the atoll is about 53 tons but sometimes drops to only 30-40 tons. These figures should be reliable but have not been otherwise verified. So far as could be learned the variation in production is not seasonal. At the current price of \$80 per ton the atoll income from outside sources is much greater than might at first appear.

Supposing the average monthly production to be 50 tons and estimating that this is produced from 2,000 acres (roughly  $5/8$  of the total atoll area) of coconuts worked for copra, the average yield would then be 0.3 tons per acre per year, not a high figure. Further, if we assume that 2,500 acres is the maximum average available for palm groves and 0.5 tons per acre per year is the maximum average yield likely to be obtained, we find that an annual production of 1,200-1,300 tons of copra is about the maximum expected output of the entire atoll under foreseeable cultural practices.

Copra production is slow and tedious business but less so when made a group activity as it often is. The fallen nuts are thrown into heaps, often using a sharp tipped "pickup stick," and husked on a flat pointed husking stake. This is of any hard wood, sometimes shod with a Japanese-made hollow steel tip, and set firmly in the ground. Later the nut is



cracked into pieces and the meat pried from the shell. All the copra manufacture observed involved artificial drying, at least in the initial stages. The shells are excellent charcoal source and this is somewhat inefficiently made by burning off the volatile matter, often in an oil drum. The charcoal is then burned beneath the rack containing the thinly spread coconut meat, the entire rack being more or less closed to conserve heat and regulate the draft to the fire. With skill, little scorching of the copra occurs. Further drying is generally by exposures to the sun, either in racks or on mats, etc. spread on the ground. The sacked copra is transported to concentration points for later shipment.

There is a wide variation in the efficiency with which different individuals produce copra but the average is low. Some of the measures for improvement are obvious: (1) As a rough estimate, perhaps one-fourth of the area now in bearing age palms is too thickly vegetated for effective nut collection. Examples of this may be seen on L'angar, Bikareij and the western portion of Ine Island as well as on Ūl-en' and Namwi Islands where reclearing is now going on. On an additional area the vegetation is dense enough to interfere to some degree. The population shifts and disturbances caused by the war are at least in part responsible for this but reclamation has been slow. The pattern of land "ownership" also leads to neglect of the areas remote from the major "operator." Bringing all suitable areas into normal production could easily increase the atoll's copra output by one-third. (2) Although the better producers are aware that sprouted nuts yield less copra, the majority seem untroubled by a high percentage of sprouting. The succulent tissue filling the cavity of the sprouting nut, "iu," is eaten but it is an expensive food in terms of copra. The mass and respiration of the external aprout itself represent sheer waste of copra without any reduction in the amount of labor

necessary to extract the remainder. Periodic gathering of the nuts and storage on sheltered racks to allow absorption of the milk and prevent sprouting is a practice long recommended elsewhere. By this means alone an increase of perhaps 10% in copra could be obtained without proportionate increase in labor. (3) A few producers have drying sheds, i.e., roofed buildings housing the dry racks, but the majority get along with cruder and often impromptu arrangements. It is undoubtedly effective to spread copra on the mat in the sun for curing or re-drying but chickens, pigs and sudden showers are attendant hazards. Widespread adoption of the best drying practice already in use in the atoll would not increase the production greatly but would reduce the labor involved and contribute to a higher quality product.

The above comments on increasing production concern only practices already known to the Arnoese and accepted, in large part, by some of them.

#### Uses as Food

The mature meat and dried copra are less used for food than might be thought. Since the fruiting occurs throughout the year the oily nut is an excellent emergency food and apparently has its greatest use in between the pandanus and breadfruit season. In many cases copra for eating is made of nuts from particular trees, apparently selected for tenderness and sweetness of the flesh. The "iu" from the sprouting nut cavity is eaten out of the hand and also baked; it is eaten in quantity when copra is being made. Coconut "cream" squeezed from the grated mature nut is widely used in cooking, particularly of the more elaborate dishes, but is of only minor importance in terms of average consumption per person. Although methods of extracting oil from copra are known, they are tedious and it appears that very little is made, despite the general demand for cooking fats and hair pomade.

The immature nuts are used in quantity for drinking, and the soft sweet

flesh is commonly eaten as well. It would be difficult to fairly estimate average consumption over the atoll, for drinking nuts are usually proffered the visitor as routine courtesy; furthermore, the use away from the villages, particularly by men working in the groves, is greater than within the populated areas. Nevertheless, the total is great and perhaps is limited chiefly by the necessity of climbing the tree and of husking the nuts if they are to be carried.

Another widely known beverage from the coconut is the palm sap, obtained from the "flower stalk." Before the flowers emerge from the large elongate bud the tip is cut off and the juice flow observed. If satisfactory the leafy covering (spathe) is wrapped with twine to prevent opening except near the tip where it is cut away, exposing the spadix within. This is also wrapped and bent downward into a container; the sap flows from the cut surface, which is renewed by cutting each time the sap is collected. To facilitate collection, palms regularly "tapped" are notched with shallow steps the length of the trunk. On Arno the fresh sugary liquid, "jekara," is drunk fresh or occasionally boiled down to a syrup having a characteristic flavor. In the latter form it can be kept for long periods, by occasionally reheating, and serves as a sweetening. According to Spoehr, on Majuro jekara is consumed in quantity but casual observations on Arno suggest that the average consumption here is quite low. The sap ferments very rapidly and, of course, provides one of the principal alcoholic drinks throughout the range of the palm. The Arnoese, although they may jest about this product "jemanin," are reluctant to concede that it might be produced by anyone on the atoll. This is understandable, if not altogether credible, for both the missionary influence and the Mandate terms have worked against demon rum.

### Other Uses

The meat from both copra and drinking nuts is often fed to chickens and pigs, either as scrap or as supplementary feeds. Surplus "iu" from copra making is also fed to pigs.

Both the husks and the large leaves of the coconut rate as major products. The dried husks, convenient in size and in abundance, are the major fuel particularly in the well settled places or where the groves are kept free of other vegetation. The husks are also the source of twine (sennet) and rope. The long vascular fibers are freed by retting the husks for at least one or two months. If let stand for only the minimum time the husks must be pounded to free the fibers whereas with longer retting the fibers can be rubbed free of the decomposed husks in seawater. The retting apparently takes place satisfactorily in salt, brackish, or fresh water for all three are used. Husks may be buried near the high tide level on stable beaches usually along the lagoon side. Inland are retting pits, "tou," dug below the groundwater level, either fresh or brackish. Often the tou is located in a natural depression and it may be only a muddy spot in an old taro pit or brackish swamp although, according to legend, a tou on Ūl-en' Island was conveniently excavated by a star.

The washed and dried fiber or coir is made into a two strand twine, sennet. Each strand is formed endlessly by repeatedly adding groups (15 to 25) of the long parallel fibers to its untwisted end, each addition and its juncture being twisted by rolling between palm and thigh. The additions are made alternately to the two strands and between additions the strands in turn are rolled together to form the twine. The product is a tough cord that may be used for lashing, as on canoes and houses, or braided into a strong and durable rope.



The palm leaves likewise provide a fiber although of much less importance than sennet. The epidermal layers of the flat upper surface of the frond midrib are stripped free of the coarse tissues below to give a strong, somewhat brittle, strap several feet long. This is chiefly used on the spot, rather than as a permanent rope, but finds considerable use. Epidermis peeled from the individual leaflets twists into long flexible fibers used chiefly for fine weaving.

The flat leaflets of the frond are readily woven and from a palm leaf an Arno resident of any age can usually produce a basket of almost any proportions. The leaflets are left attached to the portion of the midrib which serves as a rim of the basket. Although considered much inferior to the pandanus, coconut fronds and stripped leaflets can be quickly woven into matting or panels for temporary house construction. The dry matured midribs are stiff and are sometimes used as rafters in house construction. The trunk is only occasionally used in house construction. It was once common to chop a cavity in the palm base to catch water flowing down the stem. This "emmak" was further enlarged by decay and ultimately contributed to the destruction of the tree. Although these cavities are still found on older palms they have long since been supplanted by cisterns and oil drums. The juice squeezed from the green husks is considered of value in reducing the irritating properties (presumably caused by calcium oxalate crystals) in the prepared roots of *Alocasia*. If the juice is indeed effective this cannot be due to its acidity, for samples tested were above pH 5.5.

#### Factors Affecting Production

As mentioned, the red coconut scale is present as well as a leaf spot but we saw no severe infestations of either. More serious pests, such as the rhinoceros beetle, are absent. Effective quarantines would minimize the likelihood of introducing major pests found elsewhere in the Pacific, but it is



doubtful that native shipping can ever be well inspected.

Areas of "poor" coconuts are found on the islands of Namwi, Ūl-en', L'angar and Arno. On Ūl-en' a portion of the affected area is adjacent to an inland salty pool, and is said to be flooded by the highest tides. Excessive salinity also probably accounts for similar symptoms observed on the younger portions of Namwi. On L'angar a malady locally attributed to the presence of demons causes yellowing, poor fruiting and early mortality on a tract of perhaps five acres in the interior. The presence of excessive salinity is perhaps as likely as that of demons but the soil samples have not yet been analyzed for either. In traveling, small areas of yellow palm foliage have been noticed on other islands but, on the whole, salinity is only a minor problem in the coconut groves and certainly one not readily remedied.

A tract of several acres in the interior of Arno Island is characterized by early barrenness and gradual death of the palms. According to the Headman of the village this condition has always existed in the same area, the coconuts being maintained only by continuous planting. There are no visible evidences of insects or pathogens and the characteristic leaf symptoms differ from those observed in saline areas. Breadfruit trees growing among the dying palms appear to be unaffected. The appearance and depth of sandy soils do not differ from adjacent areas where palms are normal but the long persistence of the malady within definite boundaries suggests some soil relationship. These soils are relatively removed from the shore and seem to be among the oldest on the atoll; nutrient deficiency is at least a possibility and forthcoming analyses of soil samples may help clarify this problem. The exact acreage affected cannot be well estimated because of interspersions of breadfruit groves and secondary forest; these, however, are said to be so abundant because of failure of the palms. The loss in coconut production is to some degree compensated for by

growth of such other species and the simplest solution is to give up trying to grow coconuts within this area. Attempts to discover the cause of the malady would be worthwhile, however, for it may well be found on other atolls, and its amelioration may not prove difficult.

Some comments on copra production have already been made. A further need is a replacement program to eliminate older trees past the peak of bearing. If varieties superior to those now in use can be found, their establishment would logically be coupled with such a replacement program. The introduction of large fruited strains might help reduce the labor involved in copra manufacture even though no yield increase resulted. The possibility of finding higher yielding varieties is worth exploring fully but the limitations of the atoll soils and their dissimilarity from those of most commercial planting areas should be borne in mind.

#### Breadfruit, "Mā"

Wherever its origin, the breadfruit, like the coconut, is well adapted to the atoll habitat. The breadfruit is characteristic of the interiors of the wider lands although it may grow almost to the beach when conditions are suitable. It is the common tree along walks and settled areas. Its distribution is almost certainly related to the salinity of the groundwater (see report of Hydrologist) and it is not found in the narrow lands or obviously salty areas.

#### Culture

At least six well-recognized varieties are grown on this atoll. Fruit characteristics seem to be most dependable criteria for identification although leaf form is indicative except for occasional inconsistencies. No differences in tree form are associated with variety, according to the Arnoese, and there are only minor differences in season of fruiting. Two or three varieties have seeds; the remainder are seedless. Examples of varieties with seeds are the Māttata,

which has leaves cut almost to the midribs, and the Mājwan (Mijwan) with large, 3-5 lobed leaves, the lobes limited to the distal half of the leaves. Another type of the Mājwan has entire leaves. The Bātaktak is the preferred seedless variety with a large, solid fruit. It has large 5-lobed leaves, the lower lobes extending for perhaps two-thirds the length of the leaf. By contrast, the Makinono is named for the resemblance of the 7-9 narrowly lobed leaves to those of the kino fern. Its fruit is globose and regular, turning light yellow when ready.

Around the older trees young breadfruit arise from seeds and root suckers so replacement planting is often unnecessary. Trees blown over usually sprout vigorously from the root crown and stem. The idea of vegetative reproduction is understood and suckers from desirable varieties are taken to establish new trees. Despite this, varieties said to be less desirable are still abundant.

The culture of the breadfruit is even more simple than that of the coconut. Vegetation directly competing with the young trees is cut although the plant tolerates a fair amount of side shade from taller trees and is often started in small openings. The tree grows rapidly, particularly if a sprout from an existing root system, and its own dense shade soon eliminates much of the vegetation below. Thereafter no care is given except as the expanding crown comes into competition with less desirable trees which may, in the course of time, be removed.

Tree form is greatly influenced by density. In the open or with continuous removal of side competition breadfruit tends to branch low and form a massive crown. When crowded in youth the lower branches shade off and the tree has a smaller, often ragged crown and a tall columnar trunk. Such differences in older trees have interpretive value in revealing growth conditions at an

earlier period. ,

The peak of the breadfruit season is from May to July but the trees continue to bear in decreasing amounts until December. Individual trees vary in duration of yield but there is little varietal difference. As might be expected, the large crowned trees tend to be more fruitful but are not necessarily more easily harvested. To "pick" the fruit a man climbs the tree, often using a rope to reach the first branch. Most of the fruit is reached with a picking pole some 20 ft. long, having a Y-shaped end to thrust against the fruit. With it, or by hand, the fruit is detached and falls to the ground. In narrow crowned trees most of the fruit is readily seen and can be reached with the pole from the central trunk, whereas in large spreading trees much of the fruit can be reached only from more hazardous positions midway out on the larger limbs. The fruits suffer much less than might be expected from the 30 to 60 foot fall but some are marred by exudation of the gummy latex into bruised areas. Needless to say, when the trees overhanging walks are being picked the local traffic either halts or detours.

#### Used as Food

During the season of fruiting breadfruit is the single most important food on the atoll. For most purposes the green fruit is preferred and the most common means of preparation, particularly for the preferred Bātaktak variety, is baking over charcoal. After cooking the pineapple-sized fruit is scraped clean and is then ready to be eaten or carried. The fruit may be cooked in a large number of other ways, suggesting the use of both potatoes and bread. Ripe breadfruit is somewhat sweeter and has a definite fruity taste; it is prepared somewhat as a delicacy. The rather large ( $3/4$  - 1") seeds of the seeded forms are eaten with the cooked fruit but are not usually gathered for that purpose when freed by natural decay of the fruit.



Although the breadfruit is perishable it is preserved by methods analogous to ensiling. The green latex-containing epidermis is scraped away, the fruit sliced and soaked in seawater. Upon removal the material is packed tightly into leaf-lined pits and covered with leaves which are changed regularly. Before use the starchy paste is thoroughly washed in seawater to remove the fermented taste, considered undesirable by the Marshallese. Although the method produces an acceptable foodstuff and is recognized as a means for preparing for the lean months before the next breadfruit season, it does not seem that very large quantities are stored in this way.

#### Other Uses

Near the houses the freshly fallen breadfruit leaves are often gathered for wrapping fish, breadfruit paste, etc., prior to baking. The milky latex that flows abundantly from bark wounds was once used, after hardening, as calking for canoes; it is now used only when prepared materials are not available. The latex can also serve as a bird lime although this is of little consequence to present-day people. The wood of the breadfruit is moderately soft, durable and withstands alternate wetting and drying. Further, it occurs in long pieces of relatively large diameter and so is the universal choice for canoe construction. Smaller diameter pieces and, occasionally, hand worked timbers are used for house construction.

#### Factors Affecting Production

So far as observed the tree itself is free of major pests. Only occasional instances of heart rot were observed and the few dead trees seen were all past maturity. A malady affecting the fruit, resulting in a partial decay and premature drop, was reported on Arno, Ine, and L'angar Islands, but not on Ül-en'. According to Kotiel of Arno and Loban of L'angar, the malady was first observed about 1948 and affected a large number of fruits during the



following two years, becoming less severe in 1950. Examination of fallen fruit shows a portion of the surface blackened with rot extending inward. When the stem or the central axis is weakened the fruit falls prematurely. The nature of this malady and its seriousness require a thorough investigation (see report of the Entomologist).

As mentioned, the distribution of breadfruit is certainly related to ground water salinity although little is actually known concerning depth of rooting. Generally the tree reaches maximum development in the sheltered interior of wider islands but large open-grown trees are found in settled areas and occasionally very close to the beaches. It is evident that salinity in the rooting zone will be affected by permeability of the underlying materials, depth of soil above the ground water and conditions controlling the outward flow of ground water, as well as by mere distance from the beach. In some areas (e.g. the southern part of Bikareij village) the trees reach fair diameters but appear stunted in height and show dead wood in the tops. Their appearance and location suggest salinity as a cause, perhaps acting through recurring injury or root restriction during dry periods rather than by continuous exposure. In this connection breadfruit on the lower rainfall islands of the northern Marshalls is said to be much shorter than in the south. Salinity problems are generally beyond man's control and affected areas can only be avoided.

The quantity of breadfruit in the atoll appears to be more than adequate for average needs during the seasonal peak, although additional vigorous trees would increase the late season supply. In addition to establishing more trees, replacement of less desirable varieties with better, and judicious thinning in crowded groves, as on Arno Island, would augment production. Young trees not required for food production, however, might well be kept in somewhat crowded stands to improve stem form for later utilization.

In any comprehensive work with breadfruit selection for fruit characteristics and season of fruiting would be as important as for total productivity. Introduction of other varieties of Artocarpus altilis, as well as other species of the genus is certainly worth trying. The present method of harvesting the fruit appears satisfactory to all concerned but small experiments in pruning young trees to a low spreading shape would not be altogether out of place. Artificial fertilization will probably be out of the question for a long time except with locally available phosphate.

As is true also for other crop plants, the native culture of the breadfruit includes no fertilization practice. Among the store of local medicine are at least three procedures for increasing the yield of breadfruit but, whatever their effectiveness, the materials used are in much too small quantities to affect soil fertility. The course of civilization has apparently eliminated one threat to the breadfruit for black magic is no longer considered an effective means of destroying the tree, although our informant believed it was successful in the past.

#### Pandanus, "Böp"

##### Culture

Anderson considered all of the pandanus on the atoll to be varietal selections of P. tectorius and listed 16 varieties. Of these one, Böp in Kabilin̄, with white margined leaves was reputedly introduced from the Carolines (Kabilin̄) and is found only as an ornamental. Another, Edrwan, apparently includes the straight-stemmed, small-fruited "wild" types rather than being a definite variety. The remainder are recognized as established varieties, distinguished principally by fruit characteristics which the writer never mastered. Fruit shape and, particularly, the shape of the nutlets and their aggregates seem to be the significant features. Fruit size, other than Edrwan

is not; the largest fruit is borne on young trees. Likewise leaf characteristics change with age. Certain varieties, such as Anberia and Joibeb, are recognized as outstanding for eating out of hand but our informants seemed uncertain about other specific choices among the varieties.

The pandanus season begins in October, attains its peak in November and December, and falls off after January but a few fruits mature throughout the year. There seem to be no certain varietal differences in time of maturity. The varieties are reproduced vegetatively, using the long prop roots as stock. Seedling clusters from fallen or discarded nuts are common weeds in coconut groves. These volunteer pandanus are hacked down in clearing groves although larger straight stemmed trees are often left. Plantings of the pandanus are scattered as isolated trees and small groups along paths and near houses as well as on the lagoon shore or dune, as in the interior.

The pandanus seem to have a considerable tolerance for salinity and the wild form is often found in abundance on the beach rampart of the windward coasts between the *Scaevola-Messerschmidia* scrub and the coconuts. The wild forms are also common on dunes and back of sandy shores bordering the lagoon but here as elsewhere they are often replaced with cultivated varieties. Culture of the latter consists of removing competing vegetation.

#### Uses as Food

Among the more colorful sights of the atoll are brown-faced youngsters chewing on chrome-yellow pandanus segments. In the uncooked form these serve as does sugar cane elsewhere in the tropics, albeit more flavorful. Upon baking the flavor tends to change but the non-fibrous portion is more readily extracted. This somewhat mucilaginous material is also scraped free and dried; in this form it can be stored without spoilage as an emergency food. The small nuts can be extracted and cracked for the contents although this is not a very

rewarding task. The pandanus season follows upon that of the breadfruit and during its seasonal peak it is the major food but its over-all importance is considerably less than that of the breadfruit.

#### Other Uses

The leaves of the pandanus were once perhaps fully as important in the native economy as the fruit. The plain mats used as bedding, floor covering, etc., as well as decorative mats and items almost forgotten by the present generation are woven principally from pandanus leaves. The long leaves are stripped or are gathered from the ground, trimmed, rolled so the recurved cross section will be flat and stored indoors. Later the spiny midrib is removed and the blade split into segments of desired width. Color contrasts are obtained by using leaves that have cured to various degrees, by dying, and by introducing other fibers that are colored or readily dyed.

Pandanus leaves also provide the thatching material for roofs and sides of the traditional house, although to an extent this has been superceded by introduction of corrugated iron roofing under the Japanese and, temporarily, by discarded American construction materials brought from Majuro. For use the pandanus leaves are assembled into panels made by folding the leaves over a long slender support, usually a split pandanus prop root, and stitching them in place. These units, often 5 or 6 feet in width, are overlapped as shingles and tied to the house framework. Such thatching makes a satisfactory roof for about three years or so but lasts much longer as walls. According to a legend this method of using pandanus was brought to the Marshalls long ago by wandering Gilbertese; before this, the Marshallese had used the flat leaves of the fern, Asplenium nidus.

The wild pandanus, Edrwan, is also valued for its tall straight trunks, sometimes used as supports in house construction.



### Factors Affecting Production

No major pests were observed. A great many varieties of this fruit are found throughout the Pacific and it is possible that varieties superior in some respect to those now present on the atoll may be found. Production can easily be increased simply by planting more trees, however, so the objectives of any introduction should be longer bearing period and additional fruit characteristics.

### Taro and Other Araceous Plants

The native taro of the Marshallese is Cyrtosperma chamissonis, Iaraj. The more widely known Colocasia esculenta was apparently introduced by the missionaries and its native name, Kotak, came from Kusaie, probably with the plant; it is also called Hawaiian taro. Both green-stemmed and purple-stemmed colocasias are present and there probably are other varieties not observed by the writer. Two other araceous plants are here considered with the taros although definitely not included under that name: Wöt in Kabilin is a species of Xanthosoma recently introduced and is of little significance to the present agriculture. The native Wöt is Alocasia and, according to Anderson's check list, another species may be included with A. macrorhiza under this name.

### Colocasia

The introduced Hawaiian taro is valued only for its starchy "root" which by some is considered superior to the native cyrtosperma. In keeping with the Marshallese disinterest in leafy foods the edible leaves and stems are not utilized at all. In general the culture and use of colocasia are similar to those of the native taro discussed below but a few plants, possibly an upland variety, were observed growing on the well-drained soils of the island interior.

### Cyrtosperma

No varietal differences are known. The entire plant increases in size with age, however, and the huge leaves, 8-10 ft. tall of old plants may not be



immediately identified with those of the more common smaller plants.

At one time, Iarej (Iaraj) ranked with, or perhaps exceeded breadfruit and pandanus. Today the evidence of its declining importance is clear for perhaps less than one-tenth of the pits prepared for its culture are growing significant amounts of taro. These pits were excavated to the ground water level in the sandy island interiors where the water is free of salt. The pits vary in size and shape but are commonly oval or oblong with flat bottoms 20-40 ft. long and 10-20 ft. wide. Presumably the builders made use of such natural depressions as existed but it is apparent that the pits were largely man-made. Although weathering has softened the outlines, the outer rims of the pits are commonly raised somewhat above the surrounding land, marking where the excavated material was dumped. Soil profiles on these rims are shallower and younger than those adjacent. On Ül-en' Is. taro is grown in the mucky margin of a large natural depression but cannot be extended over the somewhat brackish peat that occupies most of the basin. Elsewhere the pits are concentrated in the interiors of the wider lands such as parts of Arno, L'angar and Ine Is. where constant fresh water was assured. Within these areas some pits are immediately adjacent so the spoil forms a high wall between; others are well separated. The separate pits and such random occurrence suggest no orderly construction. Certainly each pit was an undertaking of considerable magnitude, involving the excavation of one- to several hundred tons of sand with crude tools and baskets. Labon, a very old man of Arno Is., recalls that a pit was dug in the early 1900's but it seems probable that this was the last or among the last constructed on the atoll. No one else has any recollection of excavation and the condition of all observed suggests very considerable age. According to Lijömmar the pits on his land at Ine village were there at the time of his grandparents. A legend states that the pits on Arno Is. are the footprints of a man who walked across

the land.

Elsewhere in the Pacific newly excavated taro pits are prepared for use by placing quantities of organic matter in the bottom. Presumably this was also true on Arno and organic debris is still added to the pits in use. In consequence the bottom soils are calcareous mucks with the water level lying close to the surface. After heavy rains the water may stand to the depth of several inches in the pit for at least a few days. Other than planting and harvesting the principle culture of taro is weeding. Such plants as the vigorous Wedelia extend outward from the pit margins and woody species spring there also. There are relatively few plants, such as Cyperus, the fine-like Clerodendrum and Hibiscus tiliaceus, that grow directly in the wet muck. The principle reason given for not growing taro now is that its culture involves too much work, although the prepared food is preferred to rice by some.

#### Use as Food

During the breadfruit season taro is rarely eaten but is saved for the months after the pandanus peak. The larger corms are harvested as needed and boiled or baked. Other preparations (Jukjuk) are made by baking mixtures of the cooked root with sugar and coconut cream or banana. At the present level of cultivation the Cyrtosperma and colocasia together rate as a rather minor component of the diet, although important to a few families and as a general reserve.

#### Factors Affecting Growth

No major pests were noted. The typhoons of 1905 and 1918 were said to have killed taro by flooding the pits with salt water but such storms are rare. Young taro (Cyrtosperma) in pits on Arno Is. is reported to have been killed by immersion, probably complete, in fresh water following heavy rains.

Without observation elsewhere on the Marshalls it is somewhat hazardous to speculate on the reasons for the decline of taro from its former position as a major food crop. Dr. Mason has pointed out that with a decrease in the absolute powers of the Iroi, brought about by missionary and German influences, went a gradual lessening of the landholders' responsibility to his rulers. This may well have led to the neglect of the more difficult or less rewarding tasks. It was during the same period, however, that extension of the coconut groves took place; under the stimulus of the copra trade land clearing, care of coconuts and copra manufacture required much more labor than previously. Yet another factor was involved, perhaps the decisive one: the pigs introduced by the missionaries thrived and multiplied until on Arno Is., according to Labon, taro and arrowroot were almost eliminated and new coconut plantings were damaged. Probably urged by the Germans the residents in "about 1900" declared an open season on all pigs at large, an action that reduced the depredations. Nevertheless, the taro crop had been wiped out for a period. A similar story is told by Lijömmar; pigs ruined the taro near Ine and the pits were abandoned and remain largely so to this day. The destruction of taro by pigs at a time when the native agriculture was already changing may well account for the conditions noted, apart from other factors.

Elsewhere in the Marshalls taro continues to be an important food and its culture might well be encouraged on Arno, particularly since it is already well accepted and the pits are present.

#### Alocasia

Although sometimes found with the Iarej this plant is more common on protected and fertile well-drained soils. Cultivation is largely negative, consisting of not destroying it when other plants are cut. The Wöt is an emergency food, used when others are not available, as following the pandanus

season. The corm is peeled and baked a few hours but even then may be too irritating to eat because of the minute calcium oxalate crystals. Juice of the green husks of the drinking nuts is believed to lessen the irritating principle but even after treatment the root may still be inedible. There is a belief that some people know what part of the root is responsible for the irritation and hence have more success in its preparation, but there is no botanical reason to suppose this is true. Since Wöt provides an acceptable food when free of the irritating principle, some attention might be given to taxonomic and varietal differences and to methods of preparation for elsewhere in the world some highly irritating plants of this group are rendered edible by sufficient treatment. Substitution of introduced *Xanthosoma* may be much simpler.

The large leaves of Wöt and probably of Iarej as well are used for wrapping fish and other foods for baking. The flowers of Wöt have been used for perfuming oil.

Polynesian Arrowroot. "Makmök"

Tacca leontepetaloides, the "arrowroot" of the region, exists as a semi-domesticated plant, flourishing with little care wherever the soil is salt free and only moderately shaded. It is spared when other vegetation is slashed in the groves and benefits from this weeding. In densely shaded areas, such as the interior of Arno and the wartime abandoned groves on L'angar, tacca is soon eliminated as a crop; this was well recognized by the people of L'angar in explaining the small amount of tacca now found there.

Propagation scarcely offers any problems. The small rootstocks are left when the larger ones are harvested; moreover, the plant fruits abundantly. The potato-like rootstocks are sometimes stored for a short time in the pits along the beach but soon sprout. Although it is possible to eat them baked,



usually the starch is extracted. For this the clean roots are grated raw and placed in a coarse cloth bag. Water is poured through as the mixture is stirred, thus washing out the starch and leaving the fiber in the bag. The starch is collected and dried, yielding a white high quality product that can be stored.

Although not present in quantity on all islands the maknök is sufficiently abundant on the atoll to constitute an important emergency food source in addition to its normal use. Observations suggest that the latter use is limited more by the labor involved in harvesting and preparation rather than by available supply. Inasmuch as this plant is adapted, productive, and can be successfully grown beneath the coconuts, at least in the better soils, some attention might be given to devising simple equipment that would facilitate starch extraction.

#### Bananas

On L'angar there is a legend of how once during a period of starvation a man in chase of a rat carrying away a pandanus nut discovered a grove of bananas. This is reputedly the origin of a variety, Jorukwor, regarded as indigenous, and the exact spot is marked by the sleeping man -- a massive piece of protruding beachrock. There are other versions of the story but discovery of this banana is common to all. The deep moist soil of this spot is regarded as the best for bananas, and probably is, but very few grow there now. Nowhere on the atoll does the banana grow wild and it is probable that even the Jorukwor was an ancient introduction. Most of the present bananas are known to have been introduced and often the circumstances attached to the introduction are remembered, as on Arno Is. where two weeds were reputedly brought in with the soil attached to bananas introduced by German Catholic missionaries early in the century.



### Culture

The varieties of bananas now present on the atoll were not catalogued but they seem to be few. One or two cooking bananas are grown as well as one or more edible sorts; presumably all of these can be classed as varieties or sub-species of Musa paradisiaca. The Chinese banana, M. nana, is recognized as desirable because the dwarf plants are much less subject to wind injury and it would be more widely planted if seedstocks were more abundant.

The banana is propagated by means of the large offshoots. Since the number of these is usually not great under Arno conditions and one or two are often left as replacements, multiplications of seedstocks is slow. Its growth, of course, is limited to the salt free, somewhat more fertile areas protected from the wind. Bananas seem to be planted in three general areas: (1) In the house courtyards, (2) in the groves adjacent to the house, and (3) on the sides and bottoms of the taro pits.

The graveled courtyards are kept free of organic matter and leaves of the bananas are generally chlorotic because of a deficiency of available iron. Young plants, particularly, are occasionally almost completely yellow but usually survive and become greener, generally accumulating iron during wet periods when the saturated soils favors its availability. Severe deficiency increases the time required for fruiting and, of course, reduces yield. For optimum growth and yield the banana also requires moderately high levels of soil nitrogen, ordinarily not found in the courtyard locations. Occasional plants are vigorous with large dark green leaves but these exceptions suggest only that the family sanitation does <sup>not</sup> comply with the Marshallese standards.

Planting sites in the second group are only arbitrarily separated from those in the first but in general have greater shading and somewhat better soils. Acute iron deficiency is rare, although sub-acute symptoms are often

seen. Commonly pits are dug and filled with organic refuse before the shoots are planted; similarly, sand pits dug for the maintenance of walks are often filled with household rubbish, then closed and a banana planted above. Several of our soil profile pits were left open upon request for the same purpose. Such preparation is considered good practice by the more alert growers and obviously is an excellent, albeit laborious, means of providing the fertility needed by this crop. The method is used in probably no more than 25% of the plantings made. In some soils no marked benefits would be expected and in one instance detrimental effects from this method were reported.

On planting sites of the third class, bananas usually grow well with occasional weeding as the only culture. On the lower slopes and mucky bottoms of the taro pits nutrients are in fair supply and moisture abundant but most of these areas are too heavily shaded for a maximum growth.

#### Use

Writing of conditions on nearby Majuro atoll, Spoehr suggested that perhaps bananas figured more as food gifts for visiting Americans than in the local diet. On Arno the banana seems to be a well-liked fruit and is sufficiently well-regarded that many people, though not all, are willing to give it the necessary minimum culture. Though children and honored visitors occasionally monopolize the available supply, this seems to be due more to generosity and a desire to please rather than to indifference towards the fruit. The present plant numbers and yields do not seem great enough for the fruit to be of much nutritional significance for the average person but it does provide some variety in the diet.

#### Factors Affecting Production

No major insects or diseases were evident. The fruit is usually gathered green to avoid theft and damage by rats.

The effects of iron and nitrogen deficiencies have been mentioned but there is no doubt that these could be avoided or overcome. Applications of soluble iron to very yellow leaves in Ine village produced a rapid greening but such treatments are neither feasible nor necessary. Maintenance of a deep surface mulch of organic matter would eliminate deficiency of iron, as well as supplying the nitrogen and other nutrient elements required in quantity for rapid growth. Such a mulch, if composed largely of low-nitrogen material like coconut husks, might lead to temporary nitrogen deficiency through microbial tie-up of this element but the condition would be only temporary. If herbaceous or leguminous material were included in the mulch even such temporary tie-ups would be unlikely.

Production of bananas could be increased many fold simply by further plantings on the soils known to be most favorable, such as the phosphate areas, taro pits, etc., and on other soils using mulch fertilization. The principal limitation to such mulching is the labor involved in carrying the material; by scattering the plantings throughout suitable areas, rather than concentrating them, the distance to available materials can be kept very low. Around the house areas, where surface organic matter often shelters centipedes and scorpions, pits filled with organic matter would continue to be the best insurance of satisfactory growth.

#### Papaya and Lime

It is probable that the papaya was introduced on the atoll very early in the century but it is nowhere abundant. It is usually found as a somewhat neglected tree near the dwelling places and persists as much by reason of its heavy seeding as by deliberate planting. The tree often suffers from a sub-acute iron deficiency. The only variety observed has a mediocre fruit and the plant is usually allowed to grow too tall. Unless picked green the fruit is

damaged by rats. There are occasional exceptions but generally the fruit is of very minor importance.

Present interest in the fruit does not warrant much attention to it. Introduction of better varieties and provision of knowledge about their culture and vegetative propagation are the obvious needs and might bring about further acceptance of the fruit.

Large lime trees are relatively scarce but numerous younger plants were observed. The common planting site is in the shaded interiors or on taro pit slopes. Trees planted near the houses often suffer from a severe chlorosis caused by iron deficiency. The quantity of fruit produced is much too small for any significant effects on the vitamin C intake of the average individual but the lime ranks with the kino fern as the major flavoring agents used on the atoll.

Mulching or incorporation of organic matter beneath the young trees as suggested for the banana are the obvious cultural recommendations. The single variety is of good quality and apparently propagated by seed. Introduction of additional varieties is much less important than introduction of other citrus adapted to the atoll habitat.

#### Other Introduced Food Plants

The Chile pepper (Capsicum frutescens) is commonly grown near houses for its fruits which are used, though sparsely, in cooking. In a few areas (e.g. the phosphatic soil on Tak-lib Is.) an introduced pumpkin grows as a semi-wild plant; its occasional fruits are eaten. Two varieties of sweet potatoes, "Bitato", were observed but this crop is grown only rarely and is of no significance in the general diet. A small clump of sugar cane, To'o, was found growing in an old taro pit near Ine but apparently no effort is being made to increase this despite a general liking for sweets. The presence of the yautia,



Xanthosoma, was noted under the discussion of taro. A small-fruited fig, Töbro (Ficus tinctoria) introduced from Jaluit, is found occasionally on the atoll and does not appear to have spread beyond the original planting some years ago. The firm marble-sized fruits are boiled, mashed and mixed with grated coconut; thus it provides occasional variety for few individuals. A single tree of Kûrak (Inocarpus fagiferus) grows and fruits in the garden of King Tobo in Ine village and a single mango tree was planted on Arno Island after the war.

#### Other Introduced Plants

Neglecting horticultural varieties, roughly 40% of the species now recorded on the atoll have been introduced in historic times. In addition to the introduced food plants mentioned previously and a few weeds of foreign origin, several of the other exotics have some importance for the people of Arno. With their fondness for flowers they have welcomed ornamentals and here, as throughout the Pacific tropics, hibiscus and frangipangi (Plumeria) are conspicuous. Cleander, Croton, and Bougainvillea are present but rare, the latter represented by a single plant on Arno Is. Acalypha and species of Polyscias are hedge plants in Ine village, presumably by reason of Japanese introduction. Much more widely distributed are two species of Pseuderanthemum; they are used as hedge plants and the fleshy leaves of P. atropurpureum, Tirosbin (= pink tearose), are gathered as pig feed. The herb Ocimum sanctum is used for scenting coconut oil. The small pink fairy lily, Zephyranthes, blooms periodically in the graveled yards where it seems to thrive. The much larger Hymenocallis littoralis, Kiop wau (= Lily of Oahu) was presumably brought by Hawaiian missionaries but is now naturalized in the open groves. Several other garden flowers are found in smaller numbers, presumably the hardy remnants of successive waves of introductions. Similarly, a few plants of cotton, Gossypium barbadense persist though uncultivated. Another plant called "Kotin"

is the kapok tree, Ceiba pentandra; its floss is occasionally used for pillows. According to Felix, seedlings were sent to him in 1915 by a German living on Ponape. Planted on the fertile phosphatic soil of Tak-līb Isl. they have flourished and spread but the tree is not found elsewhere on the atoll.

Seeds of tomato and watermelon as well as those of a number of garden flowers were brought to the atoll as a gift to the people from Mr. Anderson. Observations on these plantings, as well as on a small garden established by the writer, indicate a very high percentage of failure. The use of artificial fertilizers, composts or mulches will be necessary for successful growth of most common garden crops. In this connection, the shallow fresh water peats of old taro pits may be used to surface small garden spots for a few preferred plants such as the tomato.

#### Indigenous Plants of Value

Virtually all the indigenous plants figured in the native materia medica and many had other uses. The loo, Hibiscus tiliaceus, is a fiber plant of value. In habit it resembles a gigantic bush and is found singly or in very small groups in moist soil and abandoned taro pits. Although here considered indigenous, its limited occurrence and lack of aggressiveness suggest that very possibly it, too, is an ancient introduction. The tall straight poles arising from the old horizontal branches are stripped for their tough inner bark. This is used as cordage or as an easily dyed fiber for mat weaving, etc. The inner bark of arme, Pipturus argenteus, was relied upon for fish lines and is still used when imported lines are not available. The bark of Triumfetta provides a colored fiber for weaving.

The grasses, Thuarea, Elusine and Paspalum, and especially the ubiquitous legume, Vigna marina, provide much of the feed consumed by chickens. The leaves of Ipomoea tuba are gathered for pigs. In addition to the uses of its tough

wood, the fruits of the mangrove, Joff, Bruguiera conjugata, is a source of the black dye used for decorating mat fibers. Likewise, roots of Morinda provide a yellow dye. The fronds of a fern, Kino, Polypodium scolopendria, are widely used for the flavor imparted to fowl, etc., baked in its leaves. The nuts from the two species of Terminalia are used occasionally but the supply is very limited. Barringtonia fruits are used as fish poison but only by children. The wood of Guttarda was used for fire plows, not much in demand at present. Prior to cooking, octopus is covered with leaves of Messerschmidia and pounded. Tests of the dried leaves (by J. B. Sumner, Cornell University), however, show no appreciable amounts of protein-decomposing enzymes.

#### LIVESTOCK

Other than dogs and cats and occasional pet pigeons and reef herons, the only domesticated animals now on the atoll are pigs and chickens, first introduced by the Germans and missionaries. Turkeys and ducks are said to have been present prior to the war.

#### Poultry

Old men still remember that before the missionaries came the jungle fowl lived in quasi-domestication on these islands; they were valued for the cockpit. Itself an ancient immigrant, brought in some forgotten canoe, the jungle fowl was absorbed by the introduced chickens although some of the plumage characteristics are still seen. The present population has resulted from a mixture of breeds, mostly now unrecognizable except for the feather pattern of the Frizzles, said to have been introduced by the Japanese. The Arnoese do not eat eggs and the chickens are kept only for meat. Body size is usually quite small and the merits of the stock are largely hardiness and the ability to forage. The chickens are kept penned only rarely and their food consist of grasses, seeds (particularly of Vigna), insects, etc., discarded coconuts and the meager

household scraps. Young chicks are sometimes fed grated coconut or coconut and chopped grass. The hens "steal" their nests; they are good mothers and commonly bring off broods of from 12 to 15 chicks. Subsequent mortality is high and three-week-old broods seldom number more than 6 to 9. Food, weather and disease doubtlessly account for many of these losses but predation by cats is probably much greater than the people concede.

Despite these hazards the chickens are abundant and of some importance as a protein source, although the use seems to be limited to special occasions. They could be more important for there is additional poultry range outside of the well populated areas. Improvement of the existing stock and practices is quite possible but only within certain limits: (1) There is no reason to emphasize egg production until the time when people accept eggs in their diet. (2) Feed supplies will continue to be much as described above, with an ample native range and only limited supplemental feeding. Additional coconut could be fed as in the Philippines, but other supplements are not in sight. Hence, feed will probably continue to limit growth. (3) Early mortality could be decidedly decreased by confinement and supplemental feeding of the chicks. Other changes in present practice cannot be expected, except possibly within the villages, for the chickens must range widely to feed. The hardiness, disease resistance and foraging ability of the present stock are necessary attributes. Thus, the only practical recommendation is introduction of males of some vigorous, fertile, medium-weight breed such as the meat-type New Hampshire to upgrade the native stock.

The Civil Administration native school at Majuro has recently imported ducks. Various breeds, including the Muscovy, should be tried for ducks are worthy of thorough trial in view of their previous presence and the possible food supply of the shallow beaches.



### Swine

The rapid increase in numbers following introduction and the consequent disastrous effects on agriculture early in the century have been mentioned in connection with taro culture. In the more populated areas pigs at large are still prohibited, although enforcement is not always strict, and there an occasional family pig is kept in a stone walled pen. In a few areas pigs range at will with consequent destruction of all edible plants.

A very rough estimate of the total number of pigs in the atoll would be between 100 and 150. Their numbers were greatly reduced during the war and some of the Guam breed were brought in during post-war rehabilitation efforts. Crosses of this adapted breed with the runty local animals have resulted in some upgrading but the effects do not seem very marked. In two instances second and third generation animals, still with 25 or 50% Guam blood, approached the local breed in size.

This directs attention to the nutritional status of the animal. Confined animals almost certainly receive a very low energy ration, unless deliberately fattened, for leaves, household scraps, etc., can seldom be fed as sufficient quantities. Coconut is virtually the only concentrate and it is not usually fed in quantity except to pigs fattened for lard production. Pigs at large appear to fare somewhat better but unless their numbers are small in relation to area ranged they soon wipe out the plants that supply their feed. It is obvious that protein intake must be minimal. Of the minerals, calcium should be adequate because of the leafy feeds and incidental ingestion of soil. The sources of phosphorus are limited although they may suffice for the low energy ration.

Thus it appears that both animal numbers and attempts to improve the breed will be restricted by the nature and amount of food available. Increasing

the area of "open range" would provide more food but would eliminate the possibility of growing tacca, bananas, taro, etc., there. Pork is a highly desirable food, providing animal protein and adding much needed variety to the diet, and the lard is valued as well. A moderate increase in the swine population is feasible but under present conditions any considerable increase would be at the expense of other foodstuffs.

#### WOOD SUPPLIES AND REQUIREMENTS

As pointed out, much of the extension of the coconut groves was at the expense of the original forested area. Thus the *Pisonias* which Agassiz commented on when he visited the atoll in 1900 are nowhere abundant now. Today there is little to show the nature of that forest at its best; the "jungle" areas in the interior of Arno and L'angar Is. are clearly secondary forest. The only wooded area that may have some affinities with the original forest is on the atypical soils of Tak-lib Is. Here are a few large *Pisonia*, *Cordia*, *Intsia* (*Afzelia*) together with other species, but the introduced *Ceiba* suggests a very considerable disturbance.

#### Forest Situations

Apart from the above it is convenient to recognize four "forest situations," although these are not valid ecological units. (1) On exposed shores and recent lands the shoreline brush is composed largely of the sprawling *Scaevola* with a variable amount of *Messerschmidia*. On sandy lagoon shores and interior saline flats *Pemphis*, or rarely *Suriana*, is more likely to dominate. This type is of value as a windbreak and some of the woody stems are used.

(2) Merging with the above is the mixed brush, consisting of *Scaevola* and *Messerschmidia* together with tree species, such as *Pandanus*, *Guettarda*, *Ochrosia*, *Ochrocarpus*, *Terminalia*, *Morinda*, *Intsia* and occasionally, *Barringtonia* and *Calophyllum*. The trees are young and the species present depend on the

degree of salinity and seed supply. Such mixtures often represent stages in the vegetational succession following disturbance by storms or clearing. Thus, without periodic cutting the trees would eventually dominate. Occasionally one finds small stands of older *Ochrosia*, *Soulamea*, *Guettarda*, or various mixtures where this has occurred. Elsewhere the mixed brush areas are transition zones; a mixture with *Pandanus* predominating is often found on the beach rampart, tapering in height from the outer shore brush to groves inland. The mixed brush types are widely distributed and provide a variety of different woods and shapes for local use.

(3) Secondary forests on the dark salt-free soils of the interior consist of *Allophyllus*, *Premna*, *Morinda*, *Pipturia* and *Guettarda*, together with the wild *Pandanus* and sometimes *Intsia* or young *Artocarpus*. *Ixora* is locally abundant on Arno Island, and *Hibiscus tiliaceus* may occur in moist spots. All of the areas of such forests are relatively young and usually they have originated as an understory in abandoned coconut or breadfruit groves. A high proportion of stems tend to be rather crooked but the stands are sufficiently dense to largely overcome this. The relatively long, small diameter poles are well suited for framing thatched houses and are readily cut and handled. Hence this forest is of value but its occurrence is limited to a few islands and there largely owes its existence to neglect. Several of these species are good timber trees elsewhere in the Pacific but on Arno the crooked stems of young trees and the sprawling form of older relics suggests this is not true on the atoll habitats. Breadfruit (*Artocarpus*) is the noteworthy exception.

(4) Several small areas of mangrove swamp occur, chiefly in inland depressions. *Bruguiera* is the principal species, forming dense pure stands on the shallow brackish peats and rocky depressions of L'angar, Tinak and other islands. Elsewhere it occurs with *Lumnitzera* in small brackish basins. The

young poles are straight but the older trees tend to be crooked and seldom exceed ten inches in diameter. On Bikareij and Namwi Is. *Bruguiera* forms small pure stands along the margins of saline flats and inlets as well as mixing with *Sonneratia*. The inland mangrove areas are nearly valueless for agriculture but are of decided importance to nearby residents as a source of tough poles and durable wood.

Other sources of small diameter poles are the woody invaders of coconut and breadfruit groves but their abundance is in proportion to the intensity of clearing. Large trees of *Pandanus*, *Calophyllum*, *Ochrosia*, *Terminalia* and *Intsia* are occasionally found as isolated individuals along protected shores or in door yards. These are usually too large to be utilized with available tools. From time to time the large breadfruit die and decay without utilization for the same reason. Root suckers of breadfruit may form colonies that occasionally, as on the Arno Is., take on the aspects of a forest stand and are excellent sources of straight workable trunks.

#### Species and Uses

A list of woody species used by the Marshallese would simply be a catalog of those occurring for almost all are utilized. The durability of *Bruguiera*, *Lumnitzera* and *Intsia* in contact with the soil, as well as the toughness of these, *Ochrocarpus* and *Calophyllum* are known. The wide use of breadfruit for canoes has been mentioned and it is worked in many other ways. Although less abundant than now formerly, *Cordia*, workable and tough, serves for the end-pieces of small canoes, and is made into paddles, platform boards, pounding bowls, hatblocks and for similar incidental carving. In addition to the breadfruit *Soulamea* provides support beams for canoe outriggers and curved pieces of it, as well as the stems of *Scaevola*, are used for the arched braces to the outrigger float. The very hard *Pemphis* is spliced on as mast tips and



onto sail poles as a bearing frog against the mast; it is also used as the protective keel. Pemphis, Randia and Ixora are made into cage-type fishtraps and Premna, Allophyllus and Lumnitzera are the preferred woods for fishing poles. Net floats have been made of the very light wood of Hibiscus tiliaceus. Straight poles or posts of almost any species are of value for house building but differences are recognized, thus Barringtonia is considered a very poor wood. Coconut is occasionally used for heavy posts but is not durable in contact with the soil.

#### Construction Requirements

The discontinuance of the wartime base on Majuro provided a bonanza of construction materials that still has its effect on the architecture and construction of Arno. The abundance of frame and frame-thatched hybrid dwellings tends to obscure the fact that housing of sawn lumber is simply not compatible with the present average income of the Arnoese. Barring other bonanzas, most of the people will go back to living in thatched houses as decay and obsolescence claim the present shanties. The few pre-war frame buildings were largely Japanese houses or stores and copra sheds. It is easy to calculate that at present-day prices there will be very little construction, even of Marshallese-size houses, with purchased lumber. Hence the need for pandanus thatch and small diameter poles for framing is likely to increase in the future. Since rainfall stored in cisterns provides the main fresh water source for the village areas, the demand for metal roofing is a reasonable one and will continue strong. Boat construction will continue to require wood, either solid breadfruit logs for outrigger canoes or sawn lumber for the more conventional small boats.

Because of the considerable difficulties of transporting wood some individuals or groups may lack but, at present, there are ample supplies of wood and thatch for building on the atoll. Continued clearing and

better maintenance of the groves will automatically reduce wood supply. Future prospects are for diminishing supplies and somewhat higher demands.

#### Future Measures

Suggested measures for improving wood supply depend to some degree on education or supervision and hence are not practicable under existing circumstances. They are: (1) Education in and encouragement of simple care of woodland areas not in conflict with agricultural use. Thus the productivity of the mangrove swamps, in terms of useful material, could be increased by simply cutting or girdling oversized and crooked trees. Breadfruit is potentially the most valuable timber tree and its planting should be encouraged beyond the need for the fruit.

(2) It is doubtful that any introduced species would be superior to breadfruit in rate of growth on general utility but Casuarina and the bamboos have special merits. The Casuarina is a strand tree, occurring on coral shores elsewhere in the Pacific and might succeed in the beach zone. The form of the tree is fair to good and the wood hard but subject to splitting. The bamboos are so generally useful elsewhere that they are worthy of extensive trials. Mr. Kessel of the Civil Government School at Majuro reported that a planting of bamboo made there has failed. There are several genera and species of bamboos, however, and these should be tried on a variety of planting sites, especially the old taro pits and, moist soils of the interiors, and on the three areas of phosphatic soils.

(3) The possibility of a small portable sawmill serving one or more atolls should not be overlooked, although admittedly a project of the future. Presumably this would entail cooperative ownership, and operation would require mechanical skills but these problems have already been met with some success in the acquisition of atoll-owned ships. The capital investment required would

amount to, say, one-fourth to one-half of the sum represented by the atoll's copra production for a single month and hence is by no means prohibitive. The real problems involved are satisfactory transport of the mill from place to place and of the logs to the mill, as well as rigorous control of cutting. The source of logs would be very largely breadfruit and coconut, the latter yielding "porcupine wood," suitable for use if kept dry. Obviously such cutting could not be permitted to reduce production of food or copra and it need not. A replacement program for overage palms and removal of over-mature or crowded breadfruit would provide a continuous supply of sawn lumber from material now largely wasted.

#### FOOD SUPPLIES AND NUTRITION

The appraisal of food supply and nutritional significance can be in only the most general terms for the writer has no estimates of productivity and consumption, nor are there nutritional data for many components of the diet. Further, our observations were for a limited period in the season of abundant food. Nevertheless, there are ample signs that at present this atoll is well supplied with food, so far as total quantity is concerned. The sustained production of copra is an obvious guarantee against near-starvation levels. The unused supplies of arrowroot, breadfruit and alocasia, the decrease in fishing and taro culture, and the rather minor attention to food storage suggest that such food shortages as occur are far from critical. There may well be times when the diet is limited to the less desirable foods or those obtained more laboriously — to "fish, crabs and copra" as was said on L'angar — but the actual calorie intake can be maintained. Further than this, some food is imported, although primarily for the high income families.

Nutrition is one of the fads of our time as well as a subject for sober investigation, and some of the recent reports on the Pacific areas contain

facile judgments on the adequacy of native diets. Without clinical evidence of deficiency or detailed appraisal of diet, supplemented with analyses, such judgments can scarcely be more than opinion. To begin with, from all accounts the Marshallese thrived fairly well on their original island diet which contained no leafy vegetables, only pandanus and possibly bananas as fruit, and certainly no milk. Rather than the original diet it is the subsequent modification of it that provides cause for concern.

From considerations in other paragraphs it is evident that the agricultural production of the atoll in terms of calories far exceeds present dietary needs, although large percentage of this is in the form of copra. Thus it may readily be calculated that about one-third (ca. 15 to 16 tons per month) of the present copra production would alone fully supply the energy requirements (2500 calories per person per day) of the entire population (1200). Although the idea of such a diet is fantastic the figure demonstrates the importance of the coconut as a reserve and points out that the amount actually consumed is only a fraction of that prepared for export. In fact the contribution of coconut to the average calorie intake is probably greater than commonly realized, for although the mature nut is scarcely eaten when other foods are available the consumption of the soft flesh of drinking nuts and of iu (cavity tissue) is very appreciable. Much of this is eaten outside of the regular meals and often away from the dwellings. It seems likely that coconut ranks near breadfruit and pandanus as major calorie sources, with the protein foods, tacca, taro, etc., and imported foodstuffs ranking well below.

There is reason to believe that fishing is carried on to a lesser extent than formerly but the principal protein sources are still fish and seafood. Pork and poultry can make but a small contribution to the average requirement. Breadfruit and taro are considered low protein foods but, according to available



analyses, if eaten in sufficient quantity to satisfy the daily calorie requirement they supply from one-fourth to one-half the established protein requirements of the normal adult, although the quality of this protein is unknown. Analyses of dried pandanus flour and preserved breadfruit from Kapingamarangi (kindly supplied by C. D. Miller, H. Denning and A. Bauer of the University of Hawaii) show the dried pandanus, and hence presumably the original fruit, to be a poor protein source. Flesh of the immature coconut may have a much higher protein-calorie ratio than the mature nutmeat.

Although concern has been expressed over the starchy diet of breadfruit and taro the Hawaiian workers have demonstrated that these foods are, in fact, much superior to white flour and rice in respect to the B vitamins and calcium. The high calcium content in araceous plants may be of no value, however, because of the presence of oxalates. Breadfruit is considered a fair source of vitamin C, even when cooked, and this may be of considerable significance in view of the quantity consumed. Assays of the two Kapingamarangi foods bear out these results and suggest that the pandanus is a fair source of vitamin A. Although fluid from the drinking nut contains relatively small amounts of accessory substances, the quantity consumed must be considered in evaluating its contribution. Fish, crabs and other seafood provide minerals and several of the vitamins, as well as proteins, in proportion to the quantity consumed. Vitamin D is presumably of little concern except for infants and some women continuously sheltered from the sun.

These considerations suggest that the adequacy of the native diet may have been maligned unduly, although estimates of the calcium, phosphorus and vitamin C status are weak. But two unhealthy trends in the dietary habits are appearing: The substitution in part of white flour, sugar and rice for the local carbohydrate sources, and the reputed reduction in fishing. Both of these

tendencies are most marked in the Ine village area because of the higher income and greater foreign contacts, and are of lesser importance in the more remote portions of the atoll. Extension of these tendencies will inevitably lead to deterioration in quality of the diet for the lack of leafy foods, fruits, and additional protein sources leaves but little margin for safety. Yet increase in purchasing power encourages such extension and it probably cannot be avoided, barring actual controls. Suggested positive measures are mandatory enrichment of flour, at such time when its potential use is sufficient to warrant this, improved fishing methods (see report of the Marine Biologist) and diversification of the present subsistence agriculture, adding new foods while encouraging use of the old to provide both variety and nutritional quality in the modified diet.

It must be pointed out that the foregoing estimate is largely based on impressions and a few analyses. Data on the actual consumption of food, both local and imported, as well as nutritional assays and related evidence, are necessary for accurate evaluation and prediction.

#### SUMMARY OF THE AGRICULTURAL SITUATION

The agriculture of the atoll is thus seen to have two aspects, subsistence and export. The present subsistence agriculture is derivative and still rests largely upon the original food plants, cultural methods and uses of native vegetation. Introduced plants have had only minor effects on the subsistence agriculture and diet. Originally, agriculture and fishing were complementary subsistence activities and to a large extent still are. The relatively small contribution of introduced animals to the diet arises from their limited number rather than local acceptance. Some of the changes occurring in the past half century or so are displacement of taro as a major food, a great increase in the cultivated area and consequent elimination of the original vegetation, greater dependence on imported goods, and the beginnings of substitution of imported for

local foods. The pattern of land holding (see report of the Anthropologist) does not always favor fullest use of the land, particularly for subsistence crops. None the less, the subsistence agriculture is largely adequate and capable of expanding to support a considerable increase in population.

The export agriculture is concerned wholly with copra, which is the product of an indigenous tree cultivated with practices that are only modifications of those employed in the native agriculture. By those concerned with the economics of such areas, increases in export agricultural values are often looked upon as the most promising means of providing the goods and services necessary for material improvement of the people. We have already estimated very grossly that for Arno about a two-fold increase in copra production is about the most that can be hoped for under existing practices. Such an increase is a worthwhile objective but a limited one, even when combined with moderate increases in quality and production efficiency. Further, prices for copra in the world markets have been subject to wide fluctuations in the past and may be in the future.

Such considerations lead to the question of producing other export crops in order to increase the total income of the area and minimize the risks inherent in a single-crop agriculture. Unfortunately the present prospect of any considerable gains by such means is exceedingly dim. In the entire Marshalls the total area of protected land suitable for such crops is small and it is scattered piecemeal, precluding any large single developments or mechanization, and complicating production and shipment. Taking Arno as representative, even in favorable rainfall regions the inherent productivity of the soils for most such crops is very low. The calcareous soils preclude some crops and without measures for maintaining or increasing fertility the success of others would be foredoomed: Finally, were a crop decided upon, discovering varieties and

cultural methods adapted to the area, the almost certain likelihood of pest control and fertility problems, and the considerable task of adapting the people's folk ways to the new crop would together require sustained skilled effort and supervision.

These and additional causes for pessimism are set forth by J. C. Ripperton in his 1946 report on Some Agricultural Aspects of Micronesia, vol. 17 of the USCC. Economics Survey of Micronesia. They are also implicit in the perceptive statement of Project No. E. 6, "Economic Development of Coral Islands" prepared for the South Pacific Commission Research Council. The one possible exception, suggested by Ripperton, is the production of fruits, truck crops, etc. on areas near American bases to supply garrison forces. Although localized in importance such markets are lucrative and this possibility should be developed fully. The price incentives, if combined with production guidance, would accelerate agricultural change in the areas influenced.

In the subsistence agriculture it is clear that many gains can readily be made and that, in addition, there are many possibilities that offer enough prospect of success to warrant some investigation. Improvement of the existing crops and crop types, cultural methods and utilization, are realizable objectives. Introduction of additional useful plants, of which there are many in the tropics, is an obvious and attractive prospect. The same considerations mentioned for new export crops apply to such introductions, however, and numerous failures are to be expected. Yet the choice is great, the investment involved is small, and a number have already been tested in part by former introductions of low islands. But even though successful, mere introduction is without value unless the plant with its culture is accepted by the people and fills an existing or created need. Moreover, plant introduction should be looked upon largely as a means of supplementing, not making over, the present adapted agriculture.



The limitations of agriculture have been mentioned. Some general and specific changes in the export and subsistence aspects have been suggested. Yet what is clearly needed for substantial improvement in this region is a long time program of on-the-ground investigation linked with education and demonstration. Both activities can be on a small scale if properly supported and staffed. At this stage, by making use of relevant information accumulated elsewhere in the tropics, well conceived empirical investigations could pay off handsomely for a time. The results will be of little value, though, without demonstration and education to bring about acceptance. Such extension activities necessarily reach beyond the questions of production to influence utilization and consumption. Thus, they might well be fitted into a larger program of education and assistance, embracing other aspects of native industry and welfare, but this is a question of administrative policy.

The people of Arno are extremely receptive to new ideas, even though subsequent retention and execution are rather less than outstanding. American technical capacity is highly regarded because of the war-time contacts, the Bikini tests and the medical successes against yaws, venereal diseases, etc. People would readily accept an extension program modeled after the familiar agricultural extension and home demonstration activities of the U. S., but adapted to their needs and level. Yet all extension work is presumptuous to some degree, implying the greater wisdom of the newer knowledge, and if such a program is not to disturb the values and the sense of security in the existing order it must be guided by anthropological as well as technical considerations.

Summarizing, for Arno Atoll we find that productive capacity in terms of value of agricultural exports is below maximum at present but this maximum is definitely limited. In terms of subsistence agriculture, the land, supplemented by the sea, is capable of sustaining a considerably higher population than is now present, provided the meager resources are used fully and intelligently.



Fig. 1 Reef platform stripped of land by the 1905 typhoon. In the center are several islets composed of remnants and rebuilt land, vegetated largely with *Scaevola* and occasional palms.



Fig. 2 Profile of Arno loamy sand, showing dark surface horizon and abrupt transition to underlying lime sands.



Fig. 3 Profile of Arno loamy sand. Occasional tongues of darker soil penetrate below the transitional zone and coconut and pandanus roots occur throughout. The edge of the spade is at ground level. Profile #8, Arno Is.

Fig. 4 Profile of Shioya sand. The brown surface soil grades into the underlying limesand. Profile #14, L'angar Island.





Fig. 5 Recently built beach rampart being colonized by *Scaevola*. The wedge shaped shrubby fringe of *Scaevola* and *Messerschmidia* in the background is typical of windward shores.



Fig. 6 Interior "flat" which is flooded by bimonthly high tides. On a slight rise in the foreground are *Messerschmidia*, *Scaevola* and chlorotic coconut seedlings. *Pemphis* lines the margins and the surrounding coconuts are on higher ground. Namwi Island.





Fig. 7 Coconut grove on narrow island. The foreground has been recently cleared; the background area is overgrown largely by *Scaevola*.



Fig. 8 Breadfruit grove in wide island interior; size is indicated by the figure in the center. At the extreme left *Hibiscus tiliaceus* is growing in a moist depression and in the opening in the foreground *Vigna marina* clambers over piled coconut husks. Ine Island.



Fig. 9 Area of poor coconuts, interior of Arno Island, showing numerous dead trunks and declining crowns. Breadfruit is growing vigorously around and within the area.



Fig. 10. Area of poor coconuts, L'angar Is. Note the sparse ground vegetation of *Fimbristylis*, *Lepturus* and *Boerhavia*, and the chlorotic palm seedlings. The larger palms fruit poorly and have discolored foliage.



Fig. 11 Iron deficiency in banana. The left side was painted with an iron solution and has largely regained its green color except where the treatment was incomplete. The right side remains extremely chlorotic and dead patches are appearing.



Fig. 12 Along the dune ridge are thatched houses with neat graveled courts. The concrete cistern in the foreground has only its roof as a catchment surface.